# Biological efficacy performance evaluation of Ballast Water Management System Trojan Marinex™ BWT 500 in land-based test

## Test plan


**Trojan Technologies**
Test plan
April 2013

| This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register | |
|---|---|
| Quality Management | BWMS Testing |
| ISO 9001 | IMO Resolution MEPC.174(58) Annex part 2 |
| Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S | Lloyd's Register |

Approved by

15-04-2013

X Jens Tørsløv

Approved by

Signed by: Jens Tørsløv

# Biological efficacy performance evaluation of Ballast Water Management System Trojan Marinex™ BWT 500 in land-based test

## Test plan

**Prepared for** **Trojan Technologies**

**Represented by** **Andrew Daley**

*DHI land-based test facility in Hundested*

| | |
|---|---|
| Project No | 11814020 |
| Classification | Confidential |

| | | |
|---|---|---|
| Author | Gitte I. Petersen | |

| | | |
|---|---|---|
| QC | Torben Madsen | |

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# 1 Project description and treatment performance objectives

## 1.1 Background and objectives

This test plan describes the biological efficacy performance evaluation of the ballast water management system (BWMS) in a land-based test. The test plan provides the project specific details, such as the selection of water types or salinities, whereas the land-based test facility and the standard procedures and analyses are described in DHI's Quality Assurance Project Plan (QAPP) and the standard operating procedures (SOPs). The QAPP is provided in Appendix A.

Trojan Technologies, manufacturer of the BWMS Trojan Marinex ™ BWT 500 has entered a contract with DHI on the biological efficacy performance evaluation of the BWMS in a land-based test.

The mailing address of Trojan Technologies is:

Trojan Technologies
London, Ontario N5V 4T7
Canada

The purpose of the performance evaluation is to assure that the BWMS is capable of meeting the ballast water discharge standard in Regulation D-2 /1/, which is also known as the IMO D-2 standard. The land-based test will be conducted in accordance with Resolution MEPC.174(58) /2/ and the U.S. Coast Guard Standards /3/.

The requirements of the IMO D-2 standard and the U.S. Coast Guard ballast water discharge standard are identical.

## 1.2 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) with the following facilities:

Mailing address:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

## 1.3 Classification society

The classification society appointed by the manufacturer for inspection and certification of the project is:

Det Norske Veritas A/S (DNV)
Veritasveien 1
NO-1363 Høvik
Norway

# 2 Project organisation and personnel responsibilities

DHI's project manager for the present BWMS performance evaluation is:

Gitte I. Petersen, Senior biologist, Ph.D.

DHI's project organisation is illustrated in Figure 2.1.

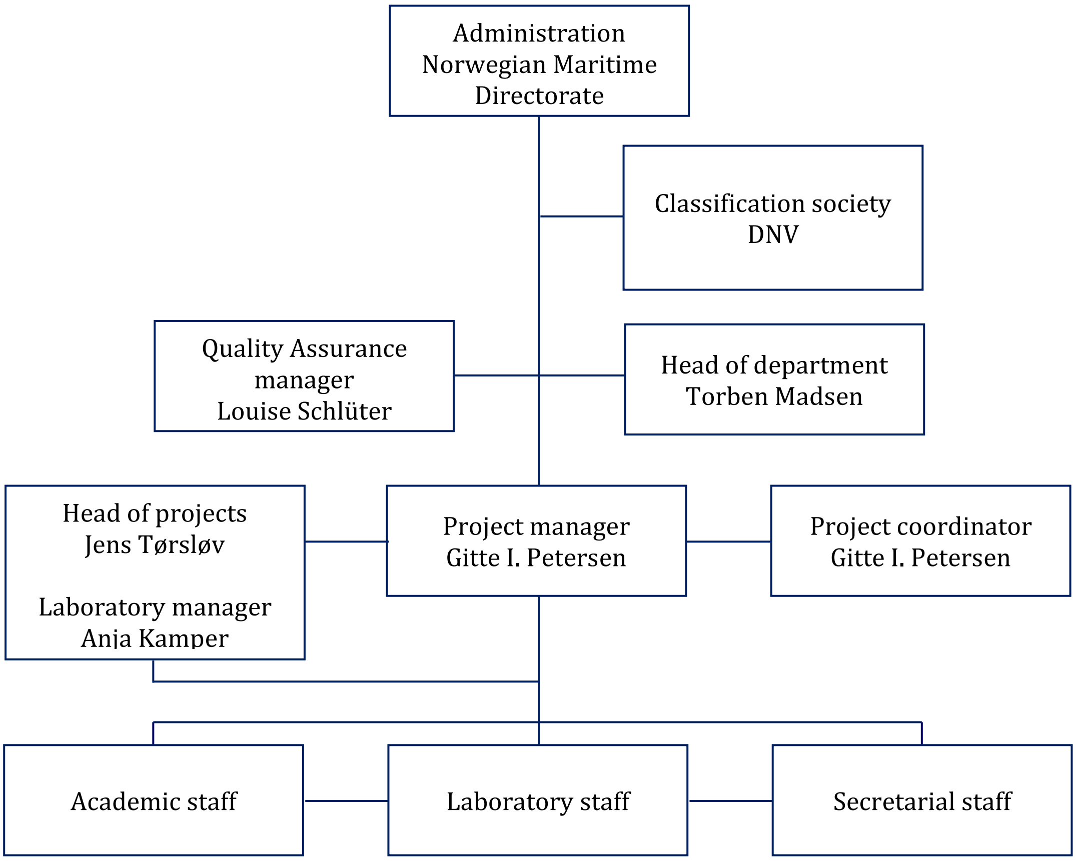



Figure 2.1 DHI's project organisation

A detailed description of the project organisation and the personnel responsibilities is provided in the QAPP.

# 3 Description of testing laboratory

A detailed description of the testing laboratory, including DHI Denmark, DHI Environmental Laboratory, DHI Maritime Technology Evaluation Facility and subcontractors, is provided in the QAPP.

# 4 Description of ballast water management system

## 4.1 Technology performance claims

Trojan Technologies states that the BWMS meets the following treatment and operation standards (with reference to the information required in the ETV protocol /4/, Section 3.2):

- The BWMS is designed to meet the ballast water discharge standard in IMO G8 /2/ and U.S. Coast Guard Standards /3/, §151.2030, which should be supported by quantitative measures of biological treatment efficacy expressed as a concentration upon discharge of the specified organism size classes.
- The biological treatment efficacy stated above can be achieved by the following quantitative measures of operational performance (e.g. the allowable and treatable flow rate and other relevant physical conditions):
  - Treatment rated capacity for one BWMS unit: 500 $m^3$/h
  - The treatment process does not need to be stopped during a filter cleaning cycle. The maritime environmental conditions, under which the BWMS can be expected to achieve the ballast water discharge standard:
    - Temperature: The BWMS works with water temperatures from -3 to 40°C (no slush or ice)
- Concentration of disinfection residuals, by-products and toxicity for relevant systems:
  - No disinfection residuals, by-products or toxicity are expected in the discharge water. Toxicity tests will be conducted to confirm this.
- The required operational and maintenance conditions (operator time, power requirements, chemical consumption requirements, reliability, etc.):
  - Please see technology and process description in Appendix B
- The projected mean time between failure for the technology given the operation and maintenance schedules provided for the technology:
  - When the given operation and maintenance schedules are adhered to, Trojan Technology does not expect failures. Projected mean times between failures cannot be estimated on the basis of the limited available experience with long-term operation.

## 4.2 Technology and process description

The technology and process description including the appropriate sections of the format for the Technical Data Package described in Section 3.10 of the ETV protocol /4/, with safety and environmental hazards and precautions, and photographs or drawings is enclosed in Appendix B.

## 4.3 Physical and electrical interfaces between the BWMS and the test facility

The BWMS will be connected to the test facility valves V20 for inlet water and V21 for treated water to retention tanks B1/B2 and/or C1/C2 (see Appendix A, QAPP, Figure 3.1). For de-ballast operations, water from retention tank B1/B2 and/or C1/C2 will be pumped to the BWMS through V20 and a separate piping section will be established for discharge of water to the harbour.

The electrical power supply to the BWMS will be delivered by the test facility generator. A cable from an onsite switchboard is connected to a socket in the BWMS. Pneumatic air is supplied to the BWMS from an external compressor.

# 5 Experimental design

## 5.1 Installation and operation of the BWMS

The manufacturer is expected to deliver the BWMS to the test facility in due time before the initiation of the performance evaluation (see Chapter 10).

The BWMS will be operated by DHI staff during all the test cycles by use of the O&M manual provided by the manufacturer as part of the Technical Data Package referred to in Chapter 4.2. The BWMS is assumed to reach a stable operating state and maintain this after no more than three start-up cycles with reference to Section 5.4.3 of the ETV protocol /4/.

To enable the independent technical operations by DHI, the manufacturer shall deliver appropriate training materials and/or practical training session(s) prior to the first test cycle.

## 5.2 Water types applied in the land-based test

The present land-based test will be conducted with the following water types:

Fresh water (salinity <1 PSU)
Brackish water (salinity 10-20 PSU)

The land-based test will include two (2) sets of biological efficacy (BE) test cycles, each consisting of five (5) replicate BE test cycles with a duration of at least five (5) days. Each set of BE test cycles will be conducted with test water representing one salinity range.

## 5.3 Biological efficacy test cycles

The BWMS will be tested at a flow rate of 500 $m^3$ per hour. Details on the BE test cycles and the associated operations are provided in the QAPP.

## 5.4 Operation and maintenance testing

O&M test will be performed as described in the QAPP.

## 5.5 Challenge conditions

The challenge conditions in the land-based test, including water quality characteristics and biological organism conditions, are described in the QAPP. The POC, DOC and TSS levels will follow the requirements stated in the ETV protocol /4/. Sodium citrate and/or lignin sulphonate will be used individually or in combination to adjust DOC and UVT to required/desired levels.

# 6 Sampling and analysis plan

## 6.1 Sample overview

Table 6.1 Overview of sampling and purpose of samples

| Parameter | Inlet water to BWMS and control tank | Treated water (1st treatment) | Treated discharge water (2nd treatment) | Control discharge water | Sample collection | Sample volume |
|---|---|---|---|---|---|---|
| Ballasting operations | | | | | | |
| Volume | × | × | × | × | Continuous | On line |
| Pressure | × | × | × | × | Continuous | On line |
| Flow | × | × | × | × | Continuous | On line |
| Other parameters* | × | × | × | × | Continuous | On line |
| Water quality conditions | | | | | | |
| Temperature, salinity, turbidity, pH, DO** | × | × | × | × | Continuous | On line |
| TSS, MM, DOC***, POC*** and UV-T**** | × | × | × | × | Discrete grab (3 replicates; time integrated) | Approx. 0.5 L |
| Concentrations of live organisms | | | | | | |
| Viable organisms ≥50 µm/m³ | ×***** | × | × | × | Discrete (3 replicates; time integrated) | Inlet: 20L Discharge: 1 m³ |
| Viable organisms ≥10 and <50 µm/mL | × | × | × | × | Discrete (3 replicates; time integrated; each representing approx. a third of the operation period) | Approx. 10 L |
| Viable organisms <10 µm/mL (heterotrophic aerobic bacteria, *E. coli*, enterococci and *Vibrio cholerae*) | × | × | × | × | Discrete grab (3 replicates; start, middle, end) | Approx. 0.5 L |
| Whole Effluent Toxicity (WET) | - | - | ×****** | ×***** | Discrete (time integrated) | Approx. 30 L |

* Operational parameters to ensure that the systems have been operated correctly and in accordance with the Operation and Maintenance manual
** Dissolved oxygen
*** Measured in inlet and discharge samples
**** UV-transmittance at 254 nm, 1 cm, measured in inlet samples
***** Collected as discrete grab samples (3 replicates; start, middle, end)
****** Only in BE test cycle No. 1. The following tests will be performed: ISO/TC 147/SC5 ISO/CD 16778 (2012). Water quality - Calanoid copepod early-life stage test with *Acartia tonsa* (5-day test); OECD TG No. 212. Fish, Short-term Toxicity Test on Embryo and sac-fry stages (10-day test)

Flow-integrated samples will be collected. The samples will be stored in thermo boxes with cooler bricks in the dark from the time of collection until handling of the samples at the DHI Environmental Laboratory.

## 6.2 Inlet water and treated water after first treatment

Table 6.2 Sampling and analysis of inlet water to BWMS and control tank

| Parameter | DHI SOP | Laboratory |
|---|---|---|
| **Organisms ≥50 µm** | 30/1700 | DHI |
| **Organisms ≥10 µm and <50 µm** | | |
| Microscopy | 30/1701 | DHI |
| Primary production (algae) | 30/1702 | DHI |
| Re-growth assay (algae) | 30/1704 | DHI |
| **Organisms <10 µm** | | |
| Heterotrophic aerobic bacteria | 30/1705 | DHI |
| **Physical/chemical** | | |
| Temperature, pH, $O_2$, salinity and turbidity | 30/1764 | DHI |
| TSS, DOC and POC | 30/1768 + 30/1769 | DHI |
| UV-transmittance at 254 nm, 1 cm | 30/1770 | DHI |

Table 6.3 Sampling and analysis of treated water after 1st treatment

| Parameter | DHI SOP | Laboratory |
|---|---|---|
| **Organisms ≥50 µm** | 30/1700 | DHI |
| **Organisms ≥10 µm and <50 µm** | | |
| Primary production (algae) | 30/1702 | DHI |
| **Organisms <10 µm** | | |
| Heterotrophic aerobic bacteria | 30/1705 | DHI |
| **Physical/chemical** | | |
| TSS | 30/1768 + 30/1769 | DHI |
| Temperature, pH, $O_2$, salinity and turbidity | 30/1764 | DHI |

## 6.3 Treated discharge water and control discharge water

Table 6.4 Sampling and analysis of treated discharge water after 2nd treatment

| Parameter | DHI SOP | Laboratory |
|---|---|---|
| **Organisms ≥50 µm** | 30/1700 | DHI |
| **Organisms ≥10 µm and <50 µm** | | |
| Microscopy | 30/1701 | DHI |
| Primary production (algae) | 30/1702 | DHI |
| Re-growth assay (algae) | 30/1704 | DHI |
| **Organisms <10 µm** | | |
| Heterotrophic aerobic bacteria | 30/1705 | DHI |
| *Vibrio cholerae* | 30/1707 | DHI |
| *E. coli* and enterococci | 30/1708 | DHI |
| **Physical/chemical** | | |
| Temperature, pH, $O_2$, salinity and turbidity | 30/1764 | DHI |
| TSS, DOC and POC | 30/1768 + 30/1769 | DHI |
| Whole Effluent Toxicity (WET)* | 30/1738 | DHI |

* To be performed on test cycle #1

Table 6.5 Sampling and analysis of control discharge water

| Parameter | DHI SOP | Laboratory |
|---|---|---|
| **Organisms ≥50 µm** | 30/1700 | DHI |
| **Organisms ≥10 µm and <50 µm** | | |
| Microscopy | 30/1701 | DHI |
| Primary production (algae) | 30/1702 | DHI |
| Re-growth assay (algae) | 30/1704 | DHI |
| **Organisms <10 µm** | | |
| Heterotrophic aerobic bacteria | 30/1705 | DHI |
| *Vibrio cholerae* | 30/1707 | DHI |
| *E. coli* and enterococci | 30/1708 | DHI |
| **Physical/chemical** | | |
| Temperature, pH, $O_2$, salinity and turbidity | 30/1764 | DHI |
| TSS, DOC and POC | 30/1768 + 30/1769 | DHI |
| Whole Effluent Toxicity (WET)* | 30/326 + 30/305 + 30/391 | DHI |

* To be performed on test cycle #1

# 7 Data management, analyses and reporting

## 7.1 Data management

The recording and storage of data are described in the QAPP.

## 7.2 Analyses

### 7.2.1 Organism size class ≥50 µm

Compliance with the pass criterion (Appendix A, QAPP, Chapter 10) will be verified by use of the direct count of live organisms ≥50 µm in minimum dimension.

The method for counting the live organisms ≥50 µm in minimum dimension is described in the QAPP.

### 7.2.2 Organism size class ≥10 µm and <50 µm

Compliance with the pass criterion (Appendix A, QAPP, Chapter 10) will be verified by use the total of viable organisms determined by measuring algal re-growth in a most probable number (MPN) assay and enumeration of viable mobile organisms ≥10 µm and <50 µm in minimum dimension that are not encompassed by the algal re-growth assay (i.e. CMFDA/FDA labelled motile organisms without chlorophyll).

The methods for counting the live organisms ≥10 and <50 µm in minimum dimension are described in the QAPP.

### 7.2.3 Organism size class <10 µm (bacteria)

Compliance with the pass criterion (Appendix A, QAPP, Chapter 10) will be verified by use of the colony forming units (CFU) enumerated on solid media. The methods for counting of bacteria are described in the QAPP.

### 7.2.4 Physical/chemical analyses

The below physical/chemical analyses will be conducted during the land-based test.

The measurements conducted at the test facility according to DHI SOPs 30/1764 and 30/1766 will include:

- pH
- Temperature
- Salinity
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- Water volume in retention tanks

During each ballast and de-ballast operation, the average UV intensity readings ($W/m^2$) displayed on the Trojan Marinex HMI-screen will be included in the DHI BE test cycle data logging procedures. The UV intensity readings will be included in relevant appendices in the final report.

Inspection of UV lamp and filter serial numbers will be performed regularly and recorded.

The analyses conducted at the DHI Environmental Laboratory will include the following measurements:

- Dissolved organic carbon (DOC)
- Particulate organic carbon (POC)
- Total suspended solids (TSS)
- UV-transmittance at 254 nm, 1 cm

## 7.3 Reporting

The following reports will be prepared:

- Interim BE test cycle report(s) compiling the data from BE test cycle(s)
- Draft final report compiling all relevant data from the test cycles, data interpretation and conclusion
- Final report

# 8 Amendments and deviations

Amendments are planned changes to the test plan. Deviations are unplanned changes. Amendments and deviations will be signed by the project manager and documented in the file and the final report.

# 9 Land-based testing requirements

The BWMS must comply with all requirements stated in Resolution MEPC.174(58) (/2/; Annex, Part 2, Section 2.3), and the U.S. Coast Guard Standards (/3/; §162.060-26).

Resolution MEPC.174(58), which is also referred to as the IMO G8 guidelines /2/, prescribes that the biological efficacy performance evaluation in the land-based test may be considered successful if the results of at least two sets of five (5) valid replicate test cycles, each set representing different salinity ranges, show discharge of treated ballast water in compliance with Regulation D-2 /1/ (see Appendix A, QAPP, Chapters 8-9). This means that a total of at least ten (10) successful test cycles must be conducted.

The U.S. Coast Guard Standards /3/ prescribe that the biological efficacy performance evaluation in the land-based test may be considered successful if the results of five (5) consecutive, valid test cycles show discharge of treated ballast water in compliance with the ballast water discharge standard (/3/; §151.2030), which is equivalent to Regulation D-2 /1/ (see Appendix A, QAPP, Chapters 8-9). The BWMS must be tested in the water conditions, for which it will be approved, and the approval certificate will list the salinity ranges, for which the BWMS is approved (/3/; §162.060-26(d,e)).

# 10 Time schedule

The testing is expected to be initiated on 2013.04.04. The following tests are expected to be performed according to the schedule given below.

| Test # | Water type | Ballast | De-ballast |
|---|---|---|---|
| 1+2 | Brackish | 2013.04.18 | 2013.04.23 |
| 3+4 | Brackish | 2013.05.02 | 2013.05.07 |
| 5 | Freshwater | 2013.05.16 | 2013.05.21 |
| 6+7 | Freshwater | 2013.05.30 | 2013.06.04 |
| 8+9 | Freshwater | 2013.06.06 | 2013.06.11 |
| 10 | Brackish | 2013.06.13 | 2013.06.18 |

The biological efficacy testing will be performed with at least one test every week or at least two tests every second week throughout the access period defined in the contract between the manufacturer and DHI, i.e. from April to June 2013.

The classification society will be updated regularly by the manufacturer or by DHI as the testing progresses.

DHI decides the applied test water salinities and the timing of the test cycles within the access period.

Dependent on weather conditions and the possibilities of preparing the right test water quality, the land-based test cycles will be conducted as outlined above.

Ballasting is performed on Thursdays from approx. 08:00 am and the de-ballasting is performed on the following Tuesday from approx. 08:00 am, if at all practicable.

A draft final report will be prepared within ten (10) weeks after successful completion of the planned test cycles.

A final report will be issued three (3) weeks after the manufacturer's approval of the draft final report.

# 11 References

/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/4/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

# Approval of test plan

**DHI Denmark**

**Project management** Date: 2013.04.15

Gitte I. Petersen

**Quality control** Date: 2013.04.15

Torben Madsen

This test plan is accepted and my signature authorizes the study to proceed as described in this document.

**Manufacturer** Date:

Andrew Daley
Trojan Technologies

# A P P E N D I X   A

Quality Assurance Project Plan

# Biological efficacy performance evaluation of Ballast Water Management Systems

## Quality Assurance Project Plan

Version 2.2
March 2013

| This report has been prepared under the DHI Business Management System certified by DNV and specifically for ballast water management system testing certified by Lloyd's Register | |
|---|---|
| Quality Management | BWMS Testing |
| ISO 9001 | IMO Resolution MEPC.174(58) Annex part 2 |
| Quality Management System certified according to DS/EN ISO 9001 by Det Norske Veritas, Business Assurance, Danmark A/S | Lloyd's Register |

| Approved by |
|---|
| 18-03-2013<br>X<br>Approved by<br>Signed by: Torben Madsen |

# Contents

## Figures



## Tables



## Appendices

# Abbreviations

| Abbreviation | Description |
| --- | --- |
| BE | Biological efficacy |
| BWMS | Ballast water management system |
| CFU | Colony forming units |
| CMFDA | Chloromethylfluorescein diacetate |
| DANAK | Danish Accreditation and Metrology Fund |
| DNV | Det Norske Veritas |
| DOC | Dissolved organic carbon |
| DOM | Dissolved organic matter |
| DQI | Data quality indicators |
| FDA | Fluorescein diacetate |
| IMO | International Maritime Organization |
| ISPS | International Safety Port System |
| kVA | Kilovolt-ampere |
| MEPC | Marine Environment Protection Committee |
| MM | Mineral materials |
| MPN | Most probable number |
| O&M | Operation and maintenance |
| POC | Particulate organic carbon |
| POM | Particulate organic matter |
| PSU | Practical salinity units |
| QA | Quality assurance |
| QAPP | Quality Assurance Project Plan |
| QC | Quality control |
| QMP | Quality Management Plan |
| SOP | Standard operating procedure |
| TSS | Total suspended solids |
| WET | Whole effluent toxicity |

# 1 Project description and treatment performance objectives

## 1.1 Background and objectives

For an application for final approval, the IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments /1/ requires a performance evaluation of ballast water management systems (BWMS) according to the principles laid down in Resolution MEPC.174(58) /2/, generally referred to as IMO G8 guidelines, and, for systems that make use of active substances, also Resolution MEPC.169(57) /3/, generally referred to as IMO G9 guidelines. The purpose of the performance evaluation is to assure that BWMS approved by administrations are capable of meeting the ballast water performance standard in Regulation D-2 /1/, also known as the IMO D-2 standard, in land-based and shipboard evaluations and do not cause unacceptable harm to the vessel, crew, environment or public health. The U.S. Coast Guard Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters /4/ (§151.2030) establish a ballast water discharge standard similar to the IMO D-2 standard. According to the U.S. Coast Guard the test set up in land-based test cycles of BWMS must operate as described in the ETV protocol /5/.

## 1.2 Testing laboratory

The project is conducted by DHI Denmark (www.dhigroup.com) with the following facilities:

Mailing address:

DHI
Agern Allé 5
DK-2970 Hørsholm
Denmark
Att. Torben Madsen

DHI Maritime Technology Evaluation Facility
Færgevejen
DK-3390 Hundested
Denmark

DHI Denmark and its facilities are described in detail in Chapter 3.

# 2 Project organisation and personnel responsibilities

DHI's project organisation is illustrated in Figure 2.1.

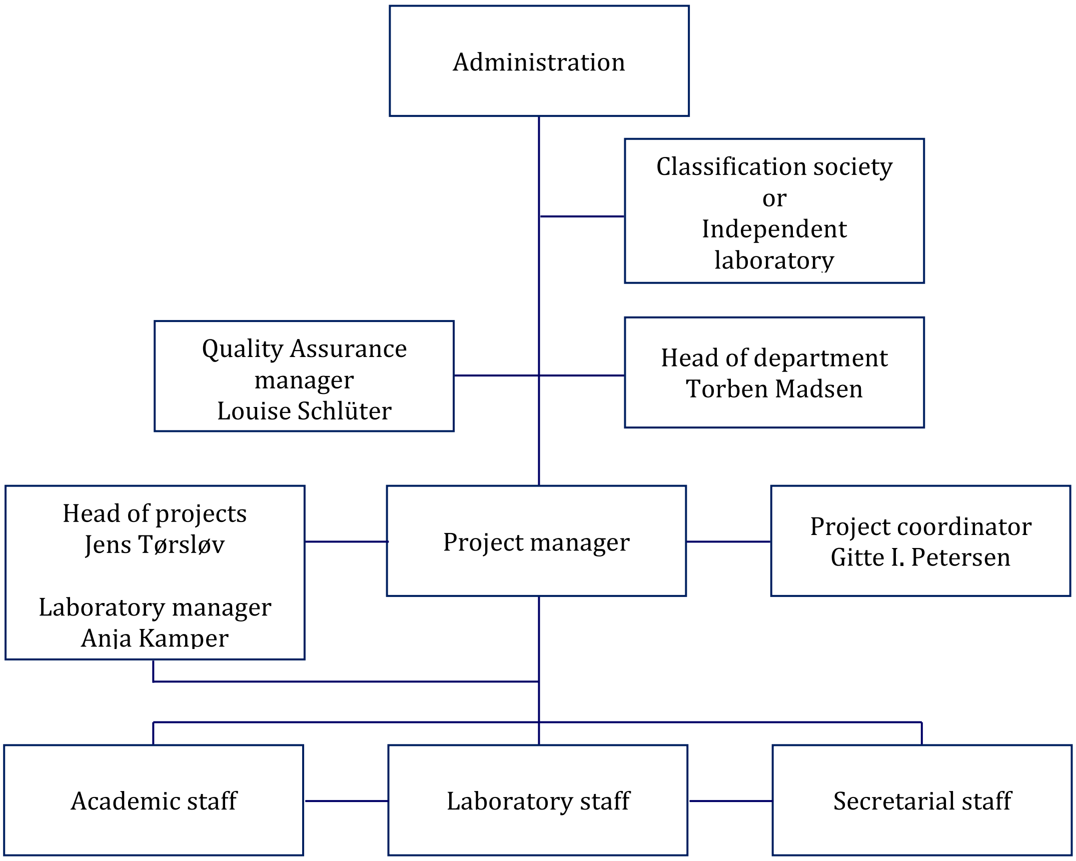



Figure 2.1 The DHI project organisation

## 2.1 Quality Assurance manager

**Senior biologist Louise Schlüter (Ph.D.)** is assigned by DHI's Quality Assurance (QA) unit as internal auditor (see Chapter 10). This includes the following tasks:

- Drafting of a plan for quality assurance
- Monitoring of compliance with the Quality Management Plan (QMP), the Quality Assurance Project Plan (QAPP), the Test Plan and the standard operating procedures (SOPs) by audit including the project manager and the laboratory staff
- Monitoring compliance with the appropriate guidelines or standards by audit including the project manager
- Verification of the presence of applicable staff training records
- Drafting of audit reports and verification that audit responses are appropriate and that corrective action has been implemented effectively
- Verification that the final product complies with DHIs standards for QA (Chapter 10) and, particularly, the QMP, the QAPP, the Test Plan and the guidelines and standards

## 2.2 Head of department

**Head of department Torben Madsen (Ph.D.)** is quality supervisor for all projects and has the overall responsibility for the services related to performance evaluation of BWMS provided by DHI Denmark. This includes the following tasks:

- Member of the Ballast Water Test Facility Board for DHI Ballast Water Centre, a coordinating structure between DHI Denmark and DHI Singapore

- Overall responsibility for the test facility and the DHI Environmental Laboratory including health and safety in the work place and decisions on investments and maintenance expenses
- Overall responsibility for the liaison and contractual relations between DHI and Lloyds Register EMEA (certification of test facility), between DHI and the Danish Accreditation and Metrology Fund, DANAK (accreditation of analyses), and between DHI and the Independent Laboratory (subcontractor agreement)
- Negotiation of contracts with manufacturers (or clients)
- Appointment of project managers and staff responsible for quality control (QC) of individual data (data-level QC) and maintenance of staff experience records (allocation of project managers for specific projects is the responsibility of the head of projects)
- Maintenance of the QAPP and the QMP /6/ with updated versions as appropriate
- Quality control of the QAPP, Test Plan, SOPs and all project proposals, deliverables and reports
- Documentation in relation to
    - Staff training and experience
    - Facilities and their maintenance
    - Records of complaints

## 2.3 Project coordinator

**Business area manager Gitte I. Petersen (Ph.D.)** is responsible for the coordination, timely execution and the overall scientific quality of the services. This includes the following tasks:

- Business development and marketing
- Contact and dialogue with Lloyds Register EMEA prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the Certificate of Compliance issued by Lloyds Register EMEA
- Contact and dialogue with the Independent Laboratory prior to inspections and for management of the actions and documentation, in collaboration with the laboratory manager, as required to comply with the agreement between DHI and the Independent Laboratory
- Coordination of the services to ensure optimal logistics at the test facility, including decisions related to the practical installation of manufacturers and their technology and timing of tests
- Maintenance of the test facility including routine technical maintenance and dialogue with the head of department in relation to investments and maintenance expenses
- Instruction of staff with responsibility for specific tasks such as test facility technical operations and production of test water
- Principal scientific expert with responsibility for the overall scientific quality of the services, including compliance with official guidelines, standards, protocols and requirements from classification societies and Independent Laboratories; this implies input to the QAPP and the Test Plan, revisions and implementation of SOPs, and contributions to data interpretation and reporting in collaboration with the project manager
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the project manager

## 2.4 Head of projects and laboratory manager

**Head of projects Jens Tørsløv (Ph.D.)** has the overall responsibility for allocation of staff, planning and project execution in coordination with the project coordinator or the project manager as appropriate.

**Laboratory manager Anja Kamper (M.Sc.)** allocates laboratory technicians for specific projects as part of the laboratory capacity planning by allocation of responsibility from the head of projects. Furthermore, the laboratory manager appoints one or more test coordinators among the laboratory technicians or the academic staff for on-site coordination of land-based test cycles.

The laboratory manager is responsible for the contact and dialogue with DANAK prior to inspections and for management of the actions and documentation as required to comply with the ISO 17025 accreditation /7/.

## 2.5 Project manager

The project manager is responsible for the management and efficient performance of the project in accordance with the Contract between the manufacturer and DHI, the QMP, the QAPP and the Test Plan.

The project manager's tasks include:

- Organisation and management of the project
- Meetings and other communication with the manufacturer to ensure that all necessary information is available in due time
- Preparation of the draft and final Test Plan with detailed description of the project, including time schedule of activities and deliverables; the QAPP and the Test Plan shall be made available to all staff participating in the project
- Facilitation of the process for comments and responses to the QAPP and the draft Test Plan in dialogue with the manufacturer and the classification society or the Independent Laboratory
- Preparation of potential amendments and deviations to the Test plan
- Communication of the project time schedule to the classification society or the Independent Laboratory to enable external audit
- Participation in discussions with the classification society or the Independent Laboratory on important matters, particularly draft and final reports, together with the Project Coordinator
- Coordination and dialogue with the laboratory manager in relation to the practical organisation of work involving laboratory technicians; the project manager shall in due time inform the laboratory manager of the types of tests and the required capacity to enable laboratory capacity planning
- Contracts with subcontractors (e.g. chemical analytical laboratory) as appropriate for meeting the project deliverables
- Approval of initiation of the test cycles and interruption of test cycles, e.g. in case of irregularity
- Preparation of reports

## 2.6 Academic, laboratory and secretarial staff

The tasks of the academic, the laboratory and the secretarial staff include:

- Maintenance of materials and equipment
- Test facility technical operations
- Test coordinator function, i.e. coordination and keeping of timely records of the activities at the test facility during land-based tests
- Production of test water and monitoring of test water quality
- Sampling at the test facility
- Analysis and data processing, including data-level QC
- Contributions to test reports
- Archiving of documents and raw data
- Contributions to QAPPs, Test Plans and SOPs

## 2.7 Manufacturer

The tasks of the representative of the manufacturer include:

- Signing a Contract with DHI for the BWMS performance evaluation project
- Project management of the manufacturers activities in the project, including the liaison with DHI and decisions in relation to the testing
- Review and comments to the draft Test Plan and approval of the final Test Plan
- Collaboration with DHI to establish all necessary arrangements prior to initiation of the test
- Review and comments to draft test reports
- Dismantling and removal of the BWMS from the test facility after ended testing

# 3 Description of testing laboratory

## 3.1 DHI Denmark

DHI is an independent, international consulting and research organisation established in Denmark and today represented in all regions of the world with a total of more than 1,000 employees. Our objectives are to advance technological development, governance and competence in the fields of water, environment and health. DHI works with governmental agencies and authorities, contractors, consultants and numerous industries.

DHI has no involvement, intellectual or financial, in the mechanics, design or marketing of the products and technologies that are being evaluated. To ensure that DHI's tests are uncompromised by any real or perceived individual or team bias relative to test outcomes, DHI's test activities are subject to rigorous quality assurance (QA), quality control (QC) and documentation.

DHI's quality management system is certified according to ISO 9001 by DNV (Det Norske Veritas). The certification is facilitated by the implementation of the DHI Business Management System (see Chapter 10).

## 3.2 DHI Environmental Laboratory

DHI's Environmental Laboratory has an accreditation according to ISO 17025 /7/ which includes ecotoxicological studies and analyses related to the performance evaluation of BWMS. Furthermore, the laboratory is authorized to carry out ecotoxicological studies in compliance with the OECD Principles of Good Laboratory Practice (GLP) /8/.

DHI's Environmental Laboratory and staff normally analyse all samples collected during the performance evaluation of BWMS. If required, specialized chemical analyses of, e.g., active substances or disinfection by-products, are conducted by a subcontractor identified in the section on Subcontractors.

## 3.3 DHI Maritime Technology Evaluation Facility

DHI holds a Certificate of Compliance issued by Lloyd's Register EMEA for the performance of land-based and shipboard testing of BWMS (Appendix A).

The travel time from the DHI Maritime Technology Evaluation Facility to the DHI Environmental Laboratory is approx. 50 min, which enables analysis or treatment of the samples within 6 hours.

The test facility is used to conduct biological evaluations of maritime technologies. The test facility is covered by the International Safety Port System (ISPS). Hundested Harbour is registered at the IMO's website (Port facilities) under Port ID No. 266076DKHUN, Port facility 1651.

The test facility includes seven cylindrical tanks constructed in galvanized steel and coated with a non-toxic top coating:

- One open 750-$m^3$ source tank, Tank D in Figure 3.1. The source tank is equipped with a propeller, which creates a slow circulation in order to maintain the homogeneity of the test water. A bridge across the top of the source tank is established for monitoring the homogeneity.
- Six closed 250-$m^3$ retention tanks, Tanks A1, B1, C1, A2, B2 and C2 in Figure 3.1. Tanks A1 and A2 are also described as 'control tanks' and are used for untreated test water. Tanks B1, C1, B2 and C2 are retention tanks for treated test water. Each of the six retention tanks is equipped with a submersible agitator (with three-blade propeller) giving the possibility to create a slow circulation in order to maintain homogeneity of the test water.

The piping connecting source tank, control tanks, retention tanks, pump and BWMS is made of polyethylene. The diameters are 315 mm and 350 mm for the piping connecting the A1, B1 and C1 tanks and 400 mm and 500 mm for the piping connecting the A2, B2 and C2 tanks.

The piping system connecting the source tank and the retention tanks is equipped with sampling ports. The sampling ports are equipped with the following sample outlets:

1. Sample outlet for ≥1-$m^3$ samples (to be used for analysis of organisms ≥50 µm)
2. Sample outlet for ≥10-L samples (to be used for analysis of organisms ≥50 µm and organisms ≥10 to <50 µm)
3. Sample outlet for microbiology samples
4. Sample outlet for samples for analysis of dissolved organic carbon (DOC), particulate organic carbon (POC), total suspended solids (TSS) and transmittance

The test facility is equipped with sensors for automatic logging of flow, pressure, water levels, temperature, dissolved oxygen, pH, salinity and turbidity.

The test facility includes a main pump with a flow performance of 250-500 $m^3$/hour. By use of a harbour piping, this pump can be used to provide a continuous flow of brackish water directly from the harbour to the BWMS with a capacity of up to approx. 300 $m^3$/hour. Furthermore, the test facility includes electrical generator power supply up to 150 kVA.

If needed to fulfil the test water quality requirements, appropriate volumes of cultivated organisms can be added to the source tank by an auxiliary pump.

The exact configuration of the test facility piping and equipment may be subject to minor changes.

The procedures, guidelines or characteristics for analyses, operations or tests performed in the DHI Environmental Laboratory, at the test facility or on board a vessel are described in the DHI SOPs.

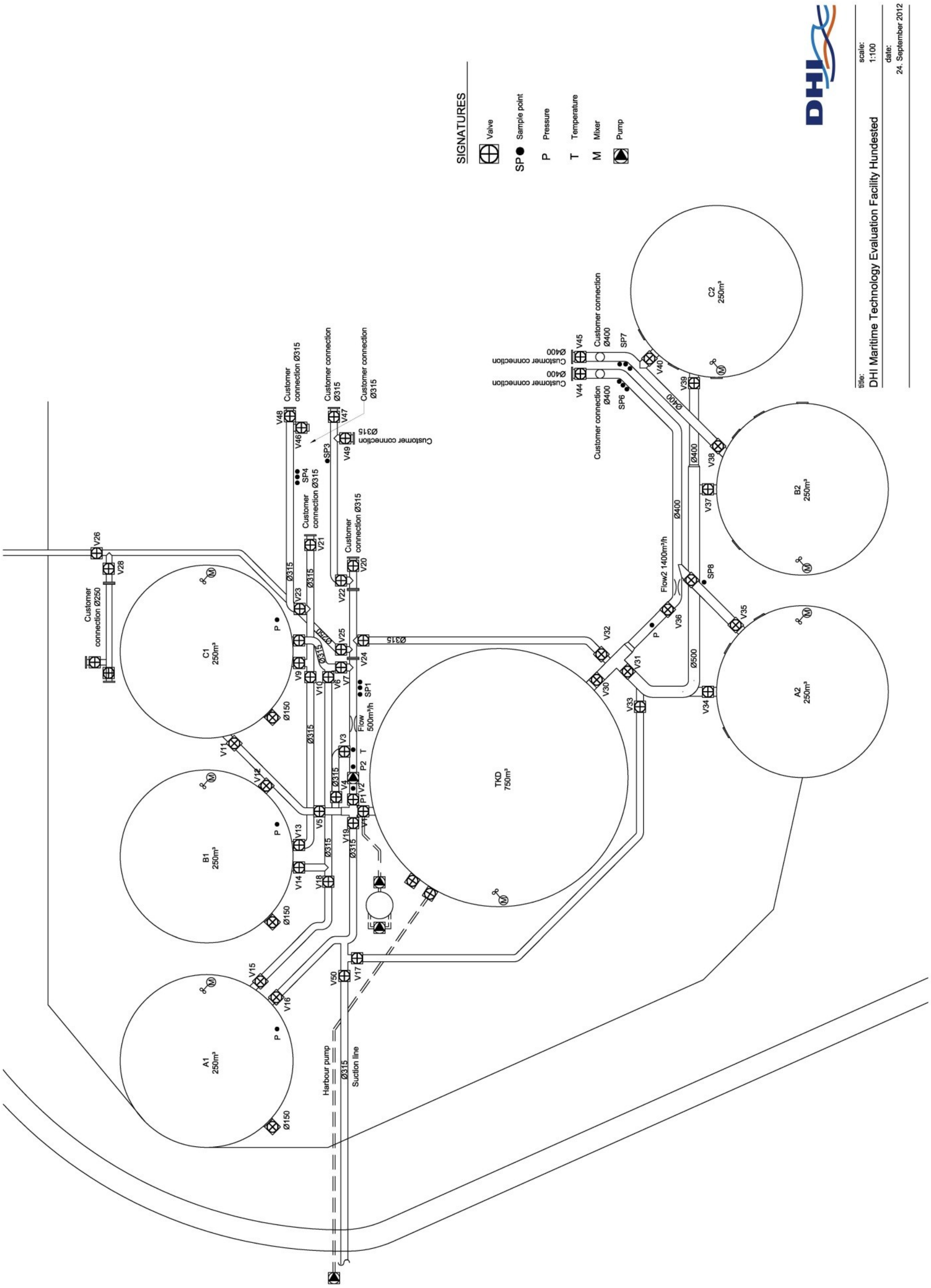



Figure 3.1 DHI Maritime Technology Evaluation Facility, Hundested, Denmark

## 3.4 Test facility equipment and calibration programmes

Test facility equipment used for analysis of physical-chemical and biological parameters is included in the ISO 17025 accreditation of DHI's Environmental Laboratory. The procedures and frequency for the calibration specific equipment are described in DHI SOPs, and compliance of the equipment with the DHI SOPs is inspected regularly by DANAK.

The test facility is equipped with an on-line monitoring system consisting of several sensors for monitoring of pressure, temperature, flow rate and water quality parameters (Table 3.1).

Table 3.1 Specification of sensor and monitoring equipment at the test facility

| No. | Function | Location | Name | Range | Serial No. | Supplier |
|---|---|---|---|---|---|---|
| 1 | Determination of water level | Bottom of source water tank D | Klay 8000-D-S-I. | 0-7.5 mwc* | 10204262 | Gustaf Fagerberg A/S |
| 2 | Determination of water level | Bottom of retention tank C1 | Klay 8000-C-S-I. | 0-5.4 mwc* | 10204265 | Gustaf Fagerberg A/S |
| 3 | Determination of water level | Bottom of retention tank B1 | Klay 8000-C-S-I. | 0-5.4 mwc* | 10204264 | Gustaf Fagerberg A/S |
| 4 | Determination of water level | Bottom of retention tank A1 | Klay 8000-C-S-I. | 0-5.4 mwc* | 10204263 | Gustaf Fagerberg A/S |
| 5 | Determination of water level | Bottom of retention tank C2 | Klay 8000-C-S-I. | 0-6.0 mwc* | 10304331 | Gustaf Fagerberg A/S |
| 6 | Determination of water level | Bottom of retention tank B2 | Klay 8000-C-S-I. | 0-6.0 mwc* | 10310814 | Gustaf Fagerberg A/S |
| 7 | Determination of water level | Bottom of retention tank A2 | Klay 8000-D-S-I. | 0-7,5 mwc* | 10304330 | Gustaf Fagerberg A/S |
| 8 | Determination of pressure in pipes before pump | P1 | Klay 8000-E-S-I | 0-3.0 bar | 10204259 | Gustaf Fagerberg A/S |
| 9 | Determination of pressure in pipes after pump | P2 | Klay 8000-F-S-I | 0-4,5 bar | 10307332 | Gustaf Fagerberg A/S |
| 10 | Determination of pressure in pipes after pump | P22 | Klay 8000-F-S-I | 0-4,5 bar | 10304329 | Gustaf Fagerberg A/S |
| 11 | Determination of pumping flow | Flow | Krohne DN300 Optiflux 2100C with electromagnetig flow converter (IFC100) | 0-600 $m^3/h$ | A0991632 | Gustaf Fagerberg A/S |
| 12 | Determination of temperature in pipes | T | Inor RBS10 PT100 (66RBS10) | 0-50°C | v033682 20101042 350120-1 | Gustaf Fagerberg A/S |
| 13 | Determination of pumping flow | Flow2 | Krohne DN400 Optiflux 2000 with electromagnetig flow converter (IFC100) | 0-1400 $m^3/h$ | A1094864 | Gustaf Fagerberg A/S |
| 14 | Determination of pH, temperature, salinity, dissolved oxygen and turbidity before treatment and control discharge | WQ.intake: Sonde equipped with flow chamber connected at relevant sampling point | YSI 6600 V2 data sonde:<br>• 6561 pH sensor<br>• 6150 ROX optical dissolved oxygen sensor<br>• 6136 turbidity sensor | n.a. | 11C 101786 | YSI inc. |
| 15 | Determination of pH, temperature, salinity, dissolved oxygen and turbidity after treatment | WQ.treated: Sonde equipped with flow chamber connected at relevant sampling point | YSI 6600 V2 data sonde:<br>• 6561 pH sensor<br>• 6150 ROX optical dissolved oxygen sensor<br>• 6136 turbidity sensor | n.a. | 11C 101787 | YSI inc. |

* Meter water column

All sensor signals are recorded via 3 Advantech ADAM-6024 modules. Each of these modules can accept 6 analogue input signals (user defined as 0/4-20 mA or ±10 volt), 2 digital input signals, 2 analogue outputs (user defined as 0/4-20 mA or ±10 volt), and 2 digital out-puts. Sensor readings are transferred to an industrial PC type (i-PC) Advantech UNO-2182 running Windows XP sp3. The i-PC is connected to the internet through a 3G modem Huawei B970. The measured data are transferred to an SQL-database running on the PLCSQL server. In the case that the i-PC loses connection to the database-server, the data will be buffered on the i-PC until connection is re-established. Once a day, backup of the database is performed and the backup file is stored on a RAID-5 NAS disk-array placed in another building than the server itself. The client server data management software program DIMS (developed by DHI) is used for handling and storage of the data.

Quality control of the on-line monitoring system is conducted by the activities described below.

The sensor for monitoring of the water level in the source tank (Tank D) is verified by measuring the height of the water columns at maximum and minimum water levels compared to the results from the sensor. Deviations of 3% and 5% are accepted at maximum and the minimum water levels, respectively.

The flow meter is verified by comparing the measured water levels in the tanks with the measured flow. A deviation of 8% is accepted. The control is performed after the sensors for determining the water level have been verified.

The pressure transmitters for monitoring the pressure in the piping are verified by reading the pressure at the maximum and the minimum water levels in the source tank (Tank D) with open piping between the transmitters and the source tank and with a closed valve behind the pressure transmitters. The monitored pressure is compared with the difference in water heights. Deviations of 3% and 5% are accepted at maximum and the minimum water level, respectively.

The thermo sensor is verified by comparing the recorded result with the temperature measured with a traceable thermometer in a time-equivalent flowing sample. A deviation of 1.0°C is accepted.

The water quality sensors are verified by checking the readings in the relevant standard solution. The following deviations are accepted: ±0.2 units for pH, 3% for dissolved oxygen, 5% for turbidity and 2% for conductivity. Verification of dissolved oxygen measurements can also be conducted by comparison between sensors and a calibrated dissolved oxygen meter. All of the water quality sensors require periodic calibration to assure high performance. The calibration is conducted at least every second week by use of the relevant standard solution.

Data for all relevant parameters are extracted from the on-line monitoring system and evaluated after each test cycle. The sensors are adjusted and calibrated again in case of non-compliance with the acceptance criteria.

## 3.5 Subcontractors

Chemical analyses:
MILANA A/S
Bakkegårdsvej 406 A
DK-3050 Humlebæk, Denmark

Microbiology; verification of *Vibrio cholerae* according to DHI SOP 30/1707:

Statens Serum Institut
Artillerivej 5
DK-2300 København S
Denmark

# 4 Description of ballast water management system

A complete description of the BWMS is provided in the Test Plan.

# 5 Performance evaluation in land-based test

## 5.1 Experimental design

### 5.1.1 Overview of test parameters

DHI's land-based test applies high quality facilities and state-of-the-art methods. A comparison of DHI's test parameters with the requirements of the IMO G8 guidelines /2/ and the ETV protocol /5/ is presented in Table 5.1.

Table 5.1 Comparison of test parameters applied by DHI and the requirements in the IMO G8 and ETV protocol

| Parameter | Sub-category | IMO G8 | ETV protocol | DHI |
|---|---|---|---|---|
| Organisms to be evaluated | Zooplankton, live organisms ≥ 50 µm in size | Naturally occurring, or cultured organisms may be added to the test water. | Ambient assemblage supplemented by the addition of standard test organisms. | Naturally occurring in the harbour outside the test facility (brackish and marine) and in Lake Arresø (fresh). For brackish and marine tests, enhanced density of natural organisms can be obtained by collection of backwash from a 10 µm mesh low pressure filter; in addition cultured organisms can be added if required. |
| | Protists, live organisms 10-50 µm in size | Naturally occurring, or cultured species that may be added to the test water. | Ambient assemblage supplemented by the addition of standard test organisms. | Naturally occurring in the harbour outside the test facility (brackish and marine) and in Lake Arresø (fresh). For brackish and marine tests, enhanced density of natural organisms can be obtained by collection of backwash from a 10 µm mesh low pressure filter; in addition cultured organisms can be added if required. |
| | Bacteria | Naturally occurring, or cultured species that may be added to the test water. | Ambient assemblage supplemented by the addition of standard test organisms. | Naturally occurring in the harbour outside the test facility (brackish and marine) and in Lake Arresø (fresh). |
| Intake organism diversity and density | Zooplankton, live organisms ≥ 50 µm in size | Organisms ≥50 µm in minimum dimension should be present in a total density of preferably $10^6$ individuals but not less than $10^5$ individuals per m³, and should consist of at least 5 species from at least 3 different phyla/divisions. | Total concentration = minimum of $1 \times 10^5$ organisms/m³. | Organisms ≥ 50 µm in minimum dimension are present in a total density above $10^5$ live individuals per m³ and consist of at least 5 species from at least 3 different phyla/divisions. |
| | Protists, live organisms C in size | Organisms ≥10 µm and less than 50 µm in minimum dimension should be present in a total density of preferably $10^4$ individuals but not less than $10^3$ individuals per ml, and should consist of at least 5 species | Organisms in the ≥10 µm and <50 µm size class must be present in minimum concentrations of $10^3$ organisms/mL with at least 5 species across 3 phyla. | Organisms ≥10 µm and less than 50 µm in minimum visible dimension are present in a total density above $10^3$ cells per mL, and consist of at least 5 species from at least 3 different phyla. |

| Parameter | Sub-category | IMO G8 | ETV protocol | DHI |
|---|---|---|---|---|
| | | from at least 3 different phyla/divisions. | | |
| | Bacteria | Heterotrophic bacteria should be present in a density of at least $10^4$ living bacteria per mL. | Organisms in the < 10 µm size class must be present in minimum concentrations of $10^3$/mL as culturable aerobic heterotrophic bacteria. | Heterotrophic bacteria are typically present in a density of at least $10^4$/mL as culturable aerobic heterotrophic bacteria. |
| Water quality of intake/source water | N/A | • Dissolved organic carbon (DOC): >5 mg/L;<br>• Particulate organic carbon (POC): >5 mg/L;<br>• Total suspended solids (TSS): >50 mg/L. | • Dissolved organic matter: min. 6 mg/L as DOC;<br>• Particulate organic matter (POM): min. 4 mg/L as POC;<br>• Mineral matter (MM): min. 20 mg/L;<br>• TSS = POM + MM: min. 24 mg/L. | Dependent season and location, typical ambient values include:<br>• DOC: 1-7 mg/L;<br>• POC: 0-2 mg/L;<br>• TSS: 1-20 mg/L.<br>DOC, POC and TSS are typically adjusted to increase levels by using lignin sulphonate, maizena and kaolin, respectively. |
| Salinity of intake/source water | N/A | • Freshwater <3 PSU;<br>• 10 PSU difference to brackish and marine | • Fresh <1 PSU;<br>• Brackish 10-20 PSU;<br>• Marine 28-36 PSU | • Fresh <1 PSU (Lake Arresø);<br>• Brackish 15-28 PSU (harbour outside the test facility);<br>• Marine 28-36 PSU (harbour water augmented by addition of brine) |
| Sample volume | Zooplankton, live organisms ≥ 50 µm in size | At least 20 L of intake water and 1 $m^3$ of treated water. | Minimum of 3 $m^3$ concentrated to 1,000 mL per sample. | Dependent on Test Plan:<br>IMO G8. Inlet: At least 20 L concentrated to approx. 500 mL per sample.<br>Treatment: Minimum 1 $m^3$, concentrated to approx. 500 mL per sample.<br>USCG/ETV. Inlet: Minimum 1 $m^3$ concentrated to 500-1,000 mL<br>Treatment: Minimum 3 $m^3$ concentrated to 500-1,000 mL. |
| | Protists, live organisms ≥10-<50 µm in size | At least 1 L of intake water and 10 L of treated water. | Minimum of 3 $m^3$ concentrated to 1,000 mL per sample. | Minimum 10 L per sample. 100-500 mL sub-sample concentrated to 20 mL on treated discharge |
| | Bacteria | At least 500 mL of intake water and 500 mL of treated water. | 1,000 mL per sample. | At least 500 mL per sample* |
| Number of intake samples | Zooplankton, live organisms ≥ 50 µm in size | Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track. | 1 sample immediately prior to water entry to the control tank and 1 sample immediately before entry to the in-line BWMS, or (if control and challenge water are shown to be representative) one sample before the splitter. | IMO G8. 3 samples (start, middle, end).<br>USCG/ETV. Minimum 1x1 $m^3$ continuous time integrated concentrated to 500-1,000 mL |
| | Protists, live organisms ≥10-<50 µm in size | Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track. | 1 sample immediately prior to water entry to the control tank and 1 sample immediately before entry to the in-line BWMS, or (if control and challenge water are shown to be representative) one sample before the splitter. | 3 samples (start, middle, end) |
| | Bacteria | Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track. | 1 sample immediately prior to water entry to the control tank and 1 sample immediately before entry to the in-line BWMS, or (if control and challenge water are shown to be representative) one sample before the splitter. | 3 samples (start, middle, end) |
| Number of discharge samples | Zooplankton, live organ- | Minimum of 3 samples collected from the treat- | 1 sample from the discharge of the control tank, and 1 sample | Dependent on Test Plan:<br>IMO: 3 continuous time inte- |

| Parameter | Sub-category | IMO G8 | ETV protocol | DHI |
|---|---|---|---|---|
| | isms ≥ 50 µm in size | ment track and 3 samples collected from the control track. | from the discharge (following any treatments) of the treated water. | grated samples (min 3 × 1 $m^3$) collected from the control and treatment lines upon discharge. Representative sub-samples analysed.<br>USCG/ETV: 1 continuous time integrated sample (min 3 $m^3$) collected from the control and treatment lines upon discharge. The equivalent of an entire cubic meter of discharge water should be examined for the presence of live animals. |
| | Protists, live organisms ≥10-<50 µm in size | Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track. | 1 sample from the discharge of the control tank, and 1 sample from the discharge (following any treatments) of the treated water. | 3 × 10 L per sample (start, middle, end). 100-300 mL sub-sample concentrated to 25 mL |
| | Bacteria | Minimum of 3 samples collected from the treatment track and 3 samples collected from the control track. | 1 sample from the discharge of the control tank, and 1 sample from the discharge (following any treatments) of the treated water. | 3 × 500 mL per sample (start, middle, end). Representative sub-samples analysed. |
| Analytic end-points: Discharge density | Zooplankton, live organisms ≥ 50 µm in size | Less than 10 viable organisms per m3 greater than or equal to 50 µm in minimum dimension for treated water; more than 100 viable organisms per $m^3$ greater than or equal to 50 µm in minimum dimension for control water. | Less than 10 viable organisms per m3 greater than or equal to 50 µm in minimum dimension for treated water; more than 100 viable organisms per $m^3$ greater than or equal to 50 µm in minimum dimension for control water. | Less than 10 viable organisms per $m^3$ greater than or equal to 50 µm in minimum dimension for treated water; more than 100 viable organisms per $m^3$ greater than or equal to 50 µm in minimum dimension for control water. |
| | Protists, live organisms ≥10-<50 µm in size | Less than 10 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for treated water; more than 100 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for control water. | Less than 10 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for treated water; more than 100 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for control water. | Less than 10 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for treated water; more than 100 viable organisms per mL less than 50 µm in minimum dimension and greater than or equal to 10 µm in minimum dimension for control water. |
| | Bacteria | Less than 1 colony forming unit (CFU) per 100 mL or less than 1 CFU/1 g (wet weight) zooplankton of toxicogenic *Vibrio cholerae* (O1 and O139), less than 250 CFU/100 mL of *E. coli*, and less than 100 CFU/100 mL of intestinal enterococci for treated water | Less than 1 CFU per 100 mL or less than 1 CFU/1 g (wet weight) zooplankton of toxicogenic *Vibrio cholerae* (O1 and O139), less than 250 CFU/100 mL of *E. coli*, and less than 100 CFU/100 mL of intestinal enterococci for treated water;<br>Minimum concentration in control tank discharge is 5 x $10^2$/mL. | Less than 1 CFU per 100 mL of toxicogenic *Vibrio cholerae* (O1 and O139), less than 250 CFU/100 mL of *E. coli*, and less than 100 CFU/100 mL of intestinal enterococci for treated water;<br>More than 5 × $10^2$/mL of heterotrophic bacteria in control tank discharge. |
| Water quality measurements | N/A | pH, temperature, salinity, dissolved oxygen, TSS, DOC, POC and turbidity (NTU) should be measured at the same time that the samples are collected. | Temperature, salinity, TSS, POM, DOM, mineral matter, dissolved oxygen, pH, chlorophyll a. | pH, temperature, salinity, dissolved oxygen, and turbidity (NTU) is continually measured by on-line monitoring on intake and discharge. TSS, DOC, POC, mineral matter and primary production (indirect measure of chlorophyll a) are measured at the same time that the samples are collected |

| Parameter | Sub-category | IMO G8 | ETV protocol | DHI |
|---|---|---|---|---|
| Toxicity | N/A | Separate samples should be collected for toxicity testing of treated water, from the discharge, for systems that make use of active substances and also for those, which could reasonably be expected to result in changes to the chemical composition of the treated water such that adverse impacts to receiving waters might occur upon discharge. Tests should conducted in accordance with Resolution MEPC.126(53)) paragraphs 5.2.3 to 5.2.7 as amended. | Toxicity tests will be conducted for treatments involving biocides. Tests will be selected from a short list of U.S. EPA standard tests. | Whole effluent toxicity (WET) tests and residual by-product chemical analyses of control and treated discharge water is performed for systems involving active substances. Tests will be selected from a short list of OECD Guideline standard tests. |
| Biological sample analysis | N/A | Samples should be analysed as soon as possible after sampling, and analysed live within 6 hour or treated in such a way as to ensure that proper analysis can be performed. Widely accepted standard methods for the collection, handling, storage, and analysis of samples should be used. | Zooplankton enumeration: Concentrate using 35 µm mesh plankton nets; no preservation; subsample into well plate (20 1mL wells observed); observe with dissecting microscope and probe organisms to determine live/dead status; fix with Lugol's for total counts. Phytoplankton enumeration: No preservation; stain with FDA and CMFDA; load into a Sedgewick Rafter Counting Chamber and examine under epifluorescence using a FITC narrow pass filter cube. Bacteria: Plate on appropriate media; use a DNA colony blot hybridisation for *V. cholerae.* | Zooplankton enumeration: Concentrate using 35 µm mesh plankton nets; no preservation; subsample into Borogov counting chamber, observe with dissecting microscope and probe organisms to determine live/dead status; fix with Lugol's for taxonomic evaluation. Phytoplankton enumeration:<br>1) No preservation; stain with FDA and CMFDA; load into a Sedgewick Rafter Counting Chamber and examine under epifluorescence;<br>2) Phytoplankton re-growth assay by use of most probable number (MPN) and<br>3) Measurements of phytoplankton primary production.<br>Bacteria: Enumeration of total viable heterotrophic bacteria, *E. coli*, and enterococci and preparation of colony blots for the detection of toxicogenic *V. cholerae.* |
| Flow rate | N/A | At least 200 $m^3$/hr. | At least 200 $m^3$/hr. | Up to 500 $m^3$/hr. and not lower than 100 $m^3$/hr. |
| Number and capacity of retention tanks | N/A | At least 1 control and 1 treatment tank with a minimum capacity of 200 $m^3$ each. | At least 1 control and 1 treatment tank with a minimum capacity of 200 $m^3$ each. | 2 control and 4 treatment tanks each with a capacity of 250 $m^3$. |
| Control/ treatment cycle sequence | N/A | Control and treatment cycles may be run simultaneously or sequentially. | Control and treatment cycles may be run simultaneously or sequentially. | Control and treatment cycles are typically run sequentially on uptake and on discharge |
| Retention time | N/A | At least 5 days. | Minimum of one day. | 1 to 5 days, dependent on Test Plan. |
| Number of trials | N/A | At least 5 successes. | Minimum of five consecutive valid per salinity regime. | Minimum of 5 successful test cycles per salinity regime. |
| QA/QC | N/A | Quality Management Plan (QMP) addressing the quality control management structure and policies of the testing body, including subcontractors and outside laboratories; Quality Assurance Project Plan (QAPP) addressing the | A Test Plan with detailed test objectives, specific test procedures and quality control and assurance requirement shall be developed. A QAPP (annexed to the Test Plan), is to be compiled by the Testing Organisation, with input from the vendor. The QAPP will describe the proce- | Quality Management Plan (QMP) addressing the quality control management structure and policies of DHI; Quality Assurance Project Plan (QAPP) addressing the specifics of the DHI's biological efficacy performance evaluation of BWMS, its facilities, and other conditions affecting the |

| Parameter | Sub-category | IMO G8 | ETV protocol | DHI |
|---|---|---|---|---|
| | | specifics of the ballast treatment technology to be tested, the test facility, and other conditions affecting the actual design and implementation of the required experiments. | dures for conducting a test or study according to the verification protocol requirements for the application of a ballast water treatment system at a particular site. At a minimum, the QAPP shall detail test objectives, specific test procedures (including sample and data collection, sample handling, analysis and preservation), and quality control and assurance requirements (including measures of precision, accuracy, comparability, and representativeness). | actual design and implementation of the required experiments. A Test Plan describing the project specific details reflecting the Contract between the manufacturer and DHI. |

### 5.1.2 Source water

Source water means the body of water, from which water is drawn for the land-based test. The IMO G8 guidelines /2/ and the ETV protocol /5/ describe three distinct water types that may be applied in the land-based test:

Fresh water (salinity <1 PSU)
Brackish water (salinity 10-20 PSU)
Marine water (salinity >32-36 PSU)

When fresh water is used, the source water will be collected in the Arresø Canal according to DHI SOP 30/1736 on collection of fresh water. Organism densities in the collected fresh water often exceed the minimum criteria for live organisms in test water with an order of magnitude allowing for dilution of the natural fresh water with potable water.

When brackish water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735; under normal conditions, the natural salinity of the source water will be 15-20 PSU.

When marine water is used, the source water will be collected immediately south of the pier adjacent to the test facility according to DHI SOP 30/1735, and brine will be added to achieve the required salinity.

### 5.1.3 Biological efficacy test cycles

#### 5.1.3.1 BWMS treatment process

The biological efficacy (BE) test cycles will be conducted by use of the source tank (Tank D), control tank (Tank A1 or A2) and one retention tank per test cycle (Tank B1, B2, C1 or C2) (Figure 3.1).

The following steps are involved in the treatment of the test water in the BWMS (for definition and characterisation of test water, see Section 5.2):

1. A fraction of the test water (minimum 200 $m^3$ and maximum 250 $m^3$) contained in the source tank is transferred to the BWMS by pumping and treated here, after which it is transferred to one of the retention tanks (treated water).

2. Another fraction of the same test water (minimum 200 $m^3$ and maximum 250 $m^3$) is pumped directly into the control tank without passing the BWMS (control water). The control water serves as a control of BWMS performance.

3. Piping system and sample ports are cleaned (DHI SOP 30/1763).

For each BE test cycle, a minimum operational period of one (1) hour is required although this may be extended if the flow rate are lower than 200 $m^3$ per hour (as described in Section 5.4.5 in the ETV protocol /5/). The minimum operational period may decrease if the flow rate of the BWMS is higher than 200 $m^3$ per hour.

During ballasting, the flow, pressure, temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks are recorded automatically (DHI SOP 30/1764).

Samples are collected before and after first treatment by use of the relevant sample ports. Sampling is initiated when the flow rate has reached steady-state conditions, i.e. up to 5 minutes from start of operation (DHI SOPs 30/1738 and 30/1762). The samples are labelled according to procedures described in DHI SOP 30/1750.

#### 5.1.3.2 Storage of treated and untreated test water

Following the treatment of the test water in the BWMS, the treated water is stored in the retention tank for at least five days ± 4 hours. The same storage time is applied for the control water.

#### 5.1.3.3 Second treatment and discharge of test water

1. Treated water contained in the retention tank is pumped through the BWMS for second treatment, after which it is discharged into the harbour (treated discharge water)
2. Control water contained in the control tank is discharged into the harbour (control discharge water)
3. The retention tanks, piping system and sample ports are cleaned (DHI SOP 30/1763)

During de-ballasting, the flow, pressure, water temperature, dissolved oxygen, pH, salinity, turbidity and water levels in the tanks are recorded automatically (DHI SOP 30/1764).

Samples of the treated discharge water are collected by use of the sampling ports on the BWMS discharge line whereas samples of the control discharge water are collected by use of sampling ports on the test facility discharge line. Isokinetic sampling methodology with fixed sample volumes is applied according to principles described in MEPC.173(58) (G2) /9/.

### 5.1.4 Whole effluent toxicity testing

Whole effluent toxicity (WET) tests are conducted with treated discharge water and control discharge water in connection to BE test cycles. The WET testing includes chronic ecotoxicity tests covering three trophic levels (algae, crustaceans, fish). The WET tests are conducted in accordance with OECD Test Guidelines or ISO standards:

- Algae: OECD TG No. 201. Algal growth inhibition test (72 hours)
- Crustaceans: ISO/TC 147/SC5 ISO/CD 16778 (Draft 2012) "Water quality - Calanoid copepod early-life stage test with *Acartia tonsa* (5 days)
- Crustaceans: OECD TG No. 211. Daphnia magna reproduction test (21 days)
- Fish: OECD TG No. 212. Fish, embryo sac fry test (10 days)

WET tests are included as part of the performance evaluation of BWMS in accordance with the requirements in Resolution MEPC.174(58) (IMO G8 guidelines) /2/ and Resolution MEPC.169(57) (IMO G9 guidelines) /3/. The WET tests are supplemented with chemical analyses of disinfection by-products in the case that the IMO G9 guidelines are applied.

### 5.1.5 Operation and maintenance testing

The operation and maintenance (O&M) testing of the BWMS shall distribute testing of a minimum treated volume of 10,000 $m^3$ amongst the BE test cycles. The minimum total volume for the O&M test cycles is achieved by conducting five O&M test cycles, each with a minimum treated volume of 2,000 $m^3$.

## 5.2 Challenge conditions in BE verification testing

### 5.2.1 Test water – water quality characteristics

Test water (equivalent to the term challenge water /4; 5/) means the inlet water as contained in the source tank just prior to treatment. In land-based tests, source water may be adjusted to achieve the required challenge conditions.

The natural concentrations of dissolved organic carbon (DOC), particulate organic carbon (POC) and total suspended solids (TSS) in the source water are analysed, after which the test water will be prepared to meet the water quality parameters in Table 5.2.

Table 5.2 Minimum water quality characteristics according to the IMO G8 guidelines /2/ and the ETV protocol /5/ in parentheses

| Parameter | Source water | | |
|---|---|---|---|
| | Fresh (<1 PSU) | Brackish (10-20 PSU) | Marine (>32-36 PSU) |
| Dissolved organic carbon (DOC) | ≥ 5 (6) mg/L | ≥ 5 (6) mg/L | ≥ 1 (6) mg/L |
| Particulate organic carbon (POC) | >5 mg/L | ≥ 5 mg/L | ≥ 1 (4) mg/L |
| Total suspended solid (TSS)<br>Mineral materials (MM) ≥ 20 mg/L | >50 mg/L | ≥ 50 mg/L | ≥ 1 (24) mg/L |

If necessary to obtain the stated water quality parameters, the concentrations of DOC, POC and mineral materials (MM) are increased by additions of lignin sulphonate (DOC), starch (POC) and kaolin clay (MM) as described in DHI SOP 30/1737.

### 5.2.2 Test water – biological organism conditions

The natural densities of live organisms in the source water are analysed with reference to size classes, after which the test water is prepared to meet the biological parameters in Table 5.3.

Table 5.3 Minimum densities of live organisms in the test water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

| Organism size class | Total concentration | Diversity |
|---|---|---|
| ≥50 µm | $10^5$ organisms/m$^3$ | 5 species across 3 phyla |
| ≥10 µm and <50 µm | $10^3$ organisms/mL | 5 species across 3 phyla |
| <10 µm (only ETV protocol) | $10^3$/mL as culturable aerobic hetero-trophic bacteria | Not applicable |

If necessary in order to obtain the stated minimum criteria, the densities of live organisms are increased by addition of harvested indigenous organisms and/or cultured species as described in DHI SOP 30/1734. Addition of harvested and/or cultured species is recorded in the data logging. Heterotrophic bacteria are typically present in the source water in densities exceeding the minimum criteria described in Table 5.3.

The minimum densities of live organisms in the control discharge water are presented in Table 5.4.

Table 5.4 Minimum densities of live organisms in the control discharge water according to the IMO G8 guidelines /2/ and the ETV protocol /5/

| Organism size class | Total concentration |
|---|---|
| ≥ 50 µm | 100 organisms/m$^3$ |
| ≥10 µm and < 50 µm | 100 organisms/mL |
| <10 µm (only ETV protocol) | $5 \times 10^2$/mL as culturable aerobic heterotrophic bacteria |

## 5.3 Sampling and analysis plan

A complete description of the sampling and analyses is provided in the Test Plan.

## 5.4 Analytical procedures

The specific analyses applied in the land-based test and the associated DHI SOPs are described in Chapter 7.

# 6 Performance evaluation in shipboard test

## 6.1 Experimental design

### 6.1.1 Source water

The source water used for the testing shall be representative of harbour or coastal waters. The natural densities of live organisms in the source water are analysed with reference to size classes. The densities of live organisms in the size classes ≥50 µm and ≥10 µm to <50 µm (Table 6.1) must exceed 10 times the maximum permitted values in the IMO D-2 standard /1/, which is similar to the ballast water discharge standard /4/.

Table 6.1 Minimum densities of live organisms in the source water in shipboard test according to the IMO G8 guidelines /2/ and the U.S. Coast Guard Standards /4/

| Organism size class | Total concentration | Diversity |
|---|---|---|
| ≥50 µm | 100 organisms/$m^3$ | No requirement |
| ≥10 µm and <50 µm | 100 organisms/mL | No requirement |

### 6.1.2 Biological efficacy test cycles

The organisation of the BE test cycles and the associated trial periods and locations are described in the Test Plan.

## 6.2 Sampling and analysis plan

A complete description of the sampling and analyses is provided in the Test Plan.

## 6.3 Analytical procedures

The specific analyses applied in the shipboard test and the associated DHI SOPs are described in Chapter 7.

# 7 Data management, analyses and reporting

## 7.1 Data management

During the land-based or shipboard test information is recorded in relation to

- Personnel participating in cleaning and maintenance at the test facility and collection of samples

- Operational procedures and monitoring
- Sampling and analysis

The data are recorded in accordance with the data-logging procedures described in the respective SOPs. A complete overview of the DHI SOPs used for BWMS performance evaluation in land-based or shipboard tests is presented in Appendix B.

An Access-based database and the procedures described in DHI SOP 30/1750 are used for storage of data generated from the BE test cycles and for marking completed QC of individual data. This data-level QC is made with reference to data quality indicators (DQI) described in the SOPs.

All generated data and all other records and information relevant to the quality and integrity of the performance evaluation, including a copy of the database file(s) and original raw data, is retained in the archives of DHI for a period of five years after issue of the final report.

## 7.2 Analyses

### 7.2.1 Organism size class ≥50 μm

Compliance with the pass criterion in Chapter 9 will be verified by use of the direct count of organisms ≥50 μm in minimum dimension.

The concentrations of live organisms ≥50 μm in minimum dimension are determined by use of a stereo microscope and a counting chamber according to DHI SOP 30/1700. Viable organisms are enumerated by use of standard movement and response stimuli technique. The viable organisms are characterized according to broad taxonomic groups such as crustaceans (e.g. copepods), molluscs, rotifers, worms, etc.

### 7.2.2 Organism size class ≥10 μm and <50 μm

Compliance with the pass criterion in Chapter 9 will be verified by use of a combination of methods which shall be stated in the Test Plan.

Verification of compliance with the pass criterion for the size class ≥10 and <50 μm in minimum dimension is not straight-forward, because conventional vital staining is not directly applicable for determination of live organisms of all ballast water management technologies. E.g., ultra violet (UV) radiation may kill the organisms, but the esterase activity causing the response of the vital stains chloromethylfluorescein diacetate (CMFDA) and fluorescein diacetate (FDA) is not immediately inactivated, and this will result in “false positive” counts. Therefore, a combination of methods is used to determine the concentrations of live organisms in the size class ≥10 and <50 μm.

Examples:

*For BWMS using e.g. active substance(s), compliance with the pass criterion in Chapter 9 may be verified by use of the direct count of CMFDA/FDA labelled organisms ≥10 and <50 μm in minimum dimension by use of an epifluorescence microscope.*

*For BWMS using filtration and UV radiation, compliance with the pass criterion in Chapter 9 may be verified by use of the total of viable organisms determined by measuring algal re-growth using a most probable number (MPN) assay and enumeration of viable moving organisms ≥10 and <50 μm in minimum dimension that are not encompassed by the algal re-growth assay (i.e. CMFDA/FDA labelled organisms without chlorophyll).*

To support the determination of concentrations of organisms in the ≥10 μm and <50 μm size class, a combination of the following analytical methods may be applied. The selection of methods shall be stated in the Test Plan:

**Inverted microscopy (DHI SOP 30/1701).** The concentrations of organisms and the presence of taxonomic groups in the inlet water are determined by inverted microscopy. Inverted microscopy is also be used to determine the taxonomic groups of algae that are able to grow under the conditions applied in the algal re-growth assay.

**Vital staining with CMFDA and FDA (DHI SOP 30/1701).** CMFDA and FDA are added to a subsample and, after incubation, the subsample is examined by use of a microscope under epifluorescence. Organisms labelled by either CMFDA or FDA are considered viable as described in DHI SOP 30/1701.

**Algal re-growth assay (DHI SOP 30/1704).** Viable algae are quantified by measuring re-growth in a most probable number (MPN) assay. A dilution series is prepared by adding aliquots of subsample to test tubes with liquid medium. The test tubes are incubated for 14 days at ambient temperature. The concentrations of viable algae in the inlet water, control discharge water and treated discharge water are determined by measuring of the fluorescence in the test tubes before and after incubation according to DHI SOP 30/1704. The algal re-growth assay is considered to provide the most reliable results to be used for a performance evaluation of BWMS applying UV treatment as the method is directly linked to algal growth and, thus, indicative of the ability of the organisms to establish and reproduce in the environment. The algal re-growth assay includes planktonic algae without reference to size, and, thus, it is not limited to the ≥10 µm and <50 µm size class.

**Algal primary production (DHI SOP 30/1702).** The algal primary production is determined by measuring the $^{14}C$ fixed by photosynthesis. For each field replicate, $NaH^{14}CO_3$ (2 µCi) is added to two subsamples. These subsamples are incubated for approx. 75 min under light from a light panel at ambient temperature. After incubation, the samples are filtered onto Whatman GF/D filters. The filters are transferred to glass vials, and acid is added directly to the filters to release $^{14}CO_2$. The $^{14}C$ activity remaining in the algae on the filters after acidification is quantified by liquid scintillation counting according to DHI SOP 30/1702. The algal primary production assay includes planktonic algae without reference to size, and, thus, it is not limited to the ≥10 µm and <50 µm size class.

### 7.2.3 Organism size class <10 µm (bacteria)

The concentrations of heterotrophic aerobic bacteria are determined according to DHI SOP 30/1706 (ISO 6222). *E. coli* and enterococci are analysed according to DHI SOP 30/1708. *Vibrio cholerae* is analysed according to the method described in DHI SOP 30/1707 (ISO 21872).

### 7.2.4 Physical/chemical analyses

The physical/chemical analyses conducted according to DHI SOPs 30/1764 and 30/1766 include:

**Land-based test:**

- pH
- Turbidity
- Dissolved oxygen
- Ballast system pressure
- Ballast system flow rates
- UV-transmittance at 254 nm, 1 cm
- Water volume in retention tanks

**Land-based and shipboard test:**

- Temperature
- Salinity
- Dissolved organic carbon (DOC)
- Particulate organic carbon (POC)
- Total suspended solids (TSS)

# 8 Validity criteria

## 8.1 Land-based test validity criteria

A valid BE test cycle implies that the average concentrations of viable organisms in the control discharge water exceed the minimum densities in Table 5.4:

- 100 organisms per $m^3$ for the size class ≥50 µm (IMO G8 guidelines, Annex, Part 2, Section 2.3.36 /2/; ETV protocol, Section 5.4.7.3 /5/)
- 100 organisms per mL for the size class ≥10 µm and <50 µm (IMO G8 guidelines, Annex, Part 2, Section 2.3.36 /2/; ETV protocol, Section 5.4.7.3 /5/)
- 500 per mL for the size class <10 µm (ETV protocol, Section 5.4.7.3 /5/)

The test report shall verify that the criteria for a valid BE test were met, or deviation from the criteria shall be scientifically justified (e.g., grazing by high numbers of zooplankton may imply that the required density for the size class ≥10 µm and <50 µm cannot be accomplished in the control water at discharge).

Although the water quality and the biological challenge conditions are not defined as validity criteria in the IMO G8 guidelines /2/ and the ETV protocol /5/, the test water should meet the minimum water quality characteristics in Table 5.2 and the minimum densities of live organisms and diversity ranges in Table 5.3.

The minimum water quality characteristics and the minimum densities of live organisms in the test water shall ensure that relevant challenge conditions are obtained in the BE test. The challenge conditions in Tables 5.2 and 5.3 can normally be met by the preparation of the test water, but natural variation in the composition of the source water may occasionally result in concentrations of DOC, POC and TSS or densities of live organisms that are slightly lower than the minimum values. A deviation of less that 10% below the minimum values in Tables 5.2 and 5.3 is considered relevant challenge conditions that do not impair the validity of the BE test. Any deviation in the average concentrations below 90% of the minimum values shall be clearly described and discussed in test report.

## 8.2 Shipboard test validity criteria

A valid BE test cycle implies that:

- The average concentrations of viable organisms in the source water are at least 10 times higher than the maximum permitted values in the IMO D-2 standard (IMO G8 guidelines, Annex, Part 2, Section 2.2.2.5 /2/), excepted from the requirements to bacteria, which is similar to the ballast water discharge standard (U.S. Coast Guard standards, §162.060-28 /4/). Minimum densities of live organisms are provided in Table 6.1
- The average concentrations of viable organisms in the control discharge water exceed the maximum permitted values in the IMO D-2 standard (IMO G8 guidelines, Annex, Part 2, Section 2.2.2.5 /2/) except for the requirements to bacteria, which is similar to the ballast water discharge standard (U.S. Coast Guard standards, §162.060-28 /4/).

# 9 Pass criteria

A valid BE test cycle, as part of either a land-based or a shipboard test, is regarded successful if it meets the performance standard for treated ballast water at discharge (IMO Regulation D-2 /1/ and United States Coast Guard /4/ (§151.2030)):

1. The average density of organisms larger than or equal to 50 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per $m^3$ at discharge

2. The average density of organisms smaller than 50 µm and larger than or equal to 10 µm in minimum diameter in the replicate samples shall be less than 10 viable organisms per mL at discharge

3. The average density of *Vibrio cholerae* (serotypes O1 and O139) shall be less than 1 colony forming unit (CFU) per 100 mL at discharge

4. The average density of *E. coli* in the replicate samples shall be less than 250 CFU per 100 mL at discharge

5. The average density of intestinal enterococci in the replicate samples shall be less than 100 CFU per 100 mL at discharge

# 10 Quality assurance and control

## 10.1 Quality assurance

The project is conducted in accordance with the principles of ISO 9001 by using the DHI Business Management System and the procedures in the QMP /6/.

The DHI quality manager is responsible for assigning a trained internal auditor from DHI's Quality Assurance Unit to each project in accordance with the procedures for internal audit in the DHI Business Management System (Section on Quality). The internal auditor shall not be involved in solving the specific project or in any project deliverables.

The DHI Business Management System (Section on Quality; Internal Audit) describes procedures for audit and evaluation and the process of periodic internal auditing of projects and activities including audit responsibilities and planning, auditor training and competences and audit reporting.

The DHI Business Management System (Section on Quality; Correction and Prevention) describes procedures for corrective actions, i.e. how deviations identified during operation and auditing are corrected and how future occurrence of the same deviations is prevented (preventive actions).

## 10.2 Quality control

Quality control of individual data, or data-level QC, of BWMS operational conditions, sampling and analyses is conducted with reference to data quality indicators (DQI) in the DHI SOPs by staff appointed for this task (see Section 2.2). The DQI include accuracy, precision, bias, representativeness, completeness, comparability, and sensitivity. The DQI and how they are monitored and evaluated are described in the relevant DHI SOPs.

Records of completed data-level QC are stored in an Access-based database (DHI SOP 30/1750), and a copy of the relevant database file(s) will be retained in the DHI archives for a period of five years after issue of the final report.

Quality control of the QAPP, DHI SOPs and all project proposals, deliverables and reports is conducted by management (see Section 2.2).

# 11 References


/1/ IMO. International Convention for the Control and Management of Ships' Ballast Water and Sediments. London. International Maritime Organization, 2004.

/2/ MEPC. Guidelines for Approval of Ballast Water Management Systems (G8). Resolution MEPC.174(58). Adopted 10th October 2008.

/3/ MEPC. Procedure for Approval of Ballast Water Management Systems that Make Use of Active Substances (G9). Resolution MEPC.169(57) Adopted 4th April 2008.

/4/ U.S. Coast Guard. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. Federal Register, Vol. 77, No. 57, March 23, 2012.

/5/ U.S. Environmental Protection Agency, Environmental Technology Verification Program. Generic Protocol for the Verification of Ballast Water Treatment Technology. EPA/600/R-10/146, September 2010.

/6/ Quality management plan. Performance Evaluation of Ballast Water Management Systems. DHI Denmark. Version 3.1. May 2012.

/7/ EN ISO/IEC 17025. General requirements for the competence of testing and calibration laboratories /ISO/IEC 17025, 2005.

/8/ OECD Principles of Good Laboratory Practice (as revised in 1997). Organisation for Economic Co-operation and Development (OECD), Paris. ENV/MC/CHEM (98)17.

/9/ Resolution MEPC.173(58). Adopted on 10 October 2008. Guidelines for approval of ballast water sampling (G2).

# APPENDIX A

Certificate of compliance, ISO 9001 certificate, accreditation and GLP authorisation

COPY

Certificate no: **DS/I093222-A**
Page 1 of 1

# Certificate of Compliance

Office: **Lloyd's Register EMEA**
**Copenhagen Design Support Centre, Statutory Section**
**Strandvejen 104A, 2nd floor**
**DK-2900 Hellerup**
**Denmark**

Date: **09 May 2012**

This certificate is issued to **DHI Ballast Water Centre, Denmark**

## DHI Ballast Water Centre, Denmark

The Document(s) listed in paragraph 1 of the appendix have been examined for compliance with:

- Resolution MEPC.174(58), Annex part 2

and are found to comply from quality assurance and quality control aspects subject to the following:

1.1. It is required to maintain full and accurate log files in order to demonstrate correct quality measures

1.2. The Quality Assurance Project Plan is a project specific document and should as such be subject to review and commenting prior to each project start-up.

1.3. This design appraisal document is to be kept together with quality management plan.

1.4. Subject certificate is valid until 15 June 2015.

1. The documents listed below have been examined

| Drawing No. | Rev. | Title | Status | Date |
|---|---|---|---|---|
| **Date: 07 Sep 2011** | **2.3** | **Quality Management Plan** | **B** | **09 May 2012** |

2. The documents listed below have been considered together with the submitted documents in the appraisal

| Drawing No. | Rev. | Title |
|---|---|---|
| **11810704** | **02** | **Quality Assurance Project Plan** |

Appraisal Status Key

B Examined and found to comply with §2.2, Part 2 of the annex of IMO Resolution MEPC 174 (58)

Martin Schabert
Statutory Department
Copenhagen Design Support Centre
Surveyor to Lloyd's Register EMEA

LLOYD'S REGISTER EMEA
Lloyd's Register
M. Schabert
COPENHAGEN DESIGN SUPPORT CENTRE

A member of the Lloyd's Register Group



Form 1124 (2005.02)

# DNV BUSINESS ASSURANCE

# MANAGEMENT SYSTEM CERTIFICATE

Certificate No. 109333-2012-AQ-DEN-DANAK

*This is to certify that*

**DHI Group**

*has been found to conform to the management system standard:*

**DS/EN ISO 9001:2008**

*This certificate is valid for the following product or service ranges:*

**Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health**

Locations included in the certification will appear in the appendix.

*Place and date:*
Hellerup, 2012-03-23

DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

*This certificate is valid until:*
2015-01-10

DANAK
SYSTEM Reg.nr. 5001

*The audit has been performed under the supervision of:*

Jan Carsten Schmidt
*Lead Auditor*

Jens Peter Høiseth
*Managing Director*

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

# DNV BUSINESS ASSURANCE

# APPENDIX TO CERTIFICATE

This appendix refers to certificate no. 109333-2012-AQ-DEN-DANAK

## DHI Group

Locations included in the certification are as follows:

| Site Address | Scope: |
|---|---|
| Agern Allé 5 2970 Hørsholm, Denmark | Consulting, MIKE© by DHI Software Development, Sales & Support, Solutions Software Development, Research, Development & Innovation and Laboratory Analysis, Testing & Products |
| INCUBA Science Park, Gustav Wieds Vej 10 8000 Århus, Denmark | Consulting, Solutions Software Development and Research, Development & Innovation |
| Drakegatan 6, 412 50 Göteborg, Sweden | Consulting, MIKE© by DHI Software Sales & Support |
| Kyrkogatan 3, 222 22 Lund, Sweden | Consulting, MIKE© by DHI Software Sales & Support |
| Svartmangatan 18, 111 29 Stockholm, Sweden | Consulting, MIKE© by DHI Software Sales & Support |
| Honnörsgatan 16, Box 3287, 350 53 Växjö, Sweden | Consulting, MIKE© by DHI Software Sales & Support |

*This certificate is valid until:*
2015-01-10

*The audit has been performed under the supervision of:*

Jan Carsten Schmidt
*Lead Auditor*

DANAK
SYSTEM Reg.nr. 5001

*Place and date:*
Hellerup, 2012-03-23
DET NORSKE VERITAS,
BUSINESS ASSURANCE, DANMARK A/S

Jens Peter Høiseth
*Managing Director*

Lack of fulfilment of conditions as set out in the Certification Agreement may render this certificate invalid.

ACCREDITED UNIT: DET NORSKE VERITAS, BUSINESS ASSURANCE, DANMARK A/S, TUBORG PARKVEJ 8, 2., DK-2900, HELLERUP, DANMARK, TEL:+45 39 45 48 00, WWW.DNVBA.COM

## Accreditation to testing

COPY DANAK

Company: **DHI**

**Agern Allé 5**
**DK-2970 Hørsholm**

Registration number: **26**

Valid: **24-10-2012 to 31-07-2015**

Scope:

**Testing**

**Product**

- **Biological items**
- **Chemicals and chemical products**
- **Construction products**
- **Environmental samples**

**Test Type**

- **Biological and biochemical testing**
- **Chemical testing**
- **Microbiological testing**
- **Ionising radiation and radiochemistry**
- **Sampling**

Testing is performed according to the current list of test methods approved by DANAK.

The company complies with the criteria in EN ISO/IEC 17025:2005 – General requirements for the competence of testing and calibration laboratories and demonstrates technical competence for the defined scope and the operation of a quality management system (refer joint ISO-ILAC-IAF Communiqué dated January 2009, www.danak.dk).

Issued the 24 October 2012

f. **Jesper Høy** / **Kirsten Jebjerg Andersen**

In case of any disputes, the Document in Danish language shall have priority.

Den Danske Akkrediterings- og Metrologifond

COPY DANAK

GOOD LABORATORY PRACTICE

STATEMENT OF COMPLIANCE

Laboratory inspection and study audits for compliance with the OECD Principles for Good Laboratory Practice were carried out at

Laboratory: DHI

on

Dates: 21st and 22nd October 2011

The laboratory inspection and study audits have been carried out in accordance with the regulation settled in Order No. 906 of 14th September 2009 from the Danish Ministry of Environment. The laboratory has been monitored for GLP Compliance within the following scope:

Type of products:

- *Industrial chemicals*
- *Pesticides*
- *Biocides*

Type of tests:

- *Environmental toxicity studies on aquatic and terrestrial organisms.*
- *Studies of behaviour in water, soil and air, bioaccumulation*

The laboratory was found to be operating in compliance with the OECD Principles of Good Laboratory Practice.

Date: 08 August 2012

Jesper Høy
Managing director, DANAK

Kirsten Jebjerg Andersen
GLP inspector, DANAK

Den Danske Akkrediterings-
og Metrologifond

# APPENDIX B

Overview of DHI SOPs

| SUBJECT/SUBSUBJECT | DHI SOP NO. |
|---|---|
| ANALYTICAL METHOD<br>DETERMINATION OF VIABLE ORGANISMS ≥50 µm | 30/1700 |
| ANALYTICAL METHOD<br>DETERMINATION OF VIABLE ORGANISMS ≥10 µm AND < 50 µm | 30/1701 |
| ANALYTICAL METHOD<br>DETERMINATION OF PRIMARY PRODUCTION OF MICROALGAE | 30/1702 |
| ANALYTICAL METHOD<br>DETERMINATION OF VIABLE ALGAE BY RE-GROWTH ASSAY | 30/1704 |
| MICROBIOLOGICAL TESTS<br>DETERMINATION OF TOTAL NUMBER OF BACTERIA BY EPIFLUORESCENCE MICROSCOPY | 30/1705 |
| MICROBIOLOGICAL TESTS<br>DETERMINATION OF HETEROTROPHIC PLATE COUNT | 30/1706 |
| MICROBIOLOGICAL TESTS<br>DETERMINATION OF *VIBRIO CHOLERAE* IN WATER | 30/1707 |
| MICROBIOLOGICAL TESTS<br>DETERMINATION OF TOTAL COLIFORM, E.COLI AND ENTEROCOCCI | 30/1708 |
| MEASUREMENT METHOD<br>TRO MEASUREMENT IN WATER | 30/1732 |
| HARVESTING, CULTURING AND ADDITION OF ORGANISMS | 30/1734 |
| COLLECTION OF SEAWATER | 30/1735 |
| COLLECTION OF FRESH WATER | 30/1736 |
| CRITERIA FOR TEST WATER<br>ADDITION OF DOC, POC, MM AND BRINE | 30/1737 |
| SAMPLING<br>PREPARATION, SUBSAMPLING AND TRANSPORTATION OF SAMPLES | 30/1738 |
| DATABASE<br>SAMPLES, LABELS AND DATA SHEETS | 30/1750 |
| OPERATION OF THE DHI MTEF | 30/1762 |
| CLEANING<br>RETENTION TANKS; PIPINGS AND OTHER EQUIPMENT AT TEST SITE | 30/1763 |
| MEASUREMENT METHOD<br>ON-LINE MONITORING OF PRESSURE, TEMPERATURE, FLOW RATES AND QUALITY PARAMETERS AT TEST SITE | 30/1764 |
| MEASUREMENT METHOD<br>FLUORESCENCE | 30/1765 |
| MEASUREMENT METHOD<br>TURBIDITY | 30/1766 |
| DHI MTEF<br>HEALTH AND SAFETY | 30/1767 |
| MEASUREMENT METHOD<br>DETERMINATION OF TSS | 30/1768 |
| MEASUREMENT METHOD<br>DETERMINATION OF DOC AND POC | 30/1769 |
| MEASUREMENT METHOD<br>DETERMINATION OF TRANSMITTANCE | 30/1770 |

# APPENDIX B

Description of the ballast water management system as provided by the manufacturer

SYSTEM
DESCRIPTION

# Trojan Marinex™ BWT 500

**Contents:**



## 1. Process and equipment design

### General description

Trojan Marinex™ BWT 500 is a fully integrated Ballast Water Treatment System (BWTS) specifically designed for marine environments at a treated rated capacity 500 meters cube per hour. The system is unique in that it combines two purely physical treatment processes, both filtration, and UV disinfection in one single unit. Combining the treatment processes preserves a small footprint and increases the ability to locate the system within the vessel. Having combined the treatment processes in one single unit reduces the complex interconnecting piping and the associated pressure loss.

The system operation can be fully automated and integrated into a vessels ballasting system or can be managed separately through the controls of the ballast water treatment equipment.

The starting sequence of treatment occurs when the inlet valve is opened, allowing ballast water to enter. While the system starts filling the lamp initiation sequence is activated. Additionally, at the end of the filling cycle when the system is full the lamp wiper starts a cleaning cycle. Once the system is completely full the outlet valve is opened and the treatment process begins. The system control works together with a flow transmitter and the pump of the vessel.

Filtration is the first stage in the treatment process. Filtration removes particles and larger organisms, while evenly distributing the flow of the ballast water into the UV section of the treatment unit. Filtered water flows through the UV section of the treatment unit targeting all organisms not removed in the filtration process.

The final stage of the treatment process occurs during de-ballast. Previously treated water (filtered + UV) is moved from the ballast tank to the de-ballast inlet of the treatment unit. During this final stage the water only moves through the UV portion of the treatment unit and then discharged to sea.

The Trojan Marinex™ BWT 500 consists of the following principal components;

<u>Treatment Unit</u>

- 316L stainless steel construction containing;
    - Twenty-four (24) super duplex custom designed filter elements for marine use.
    - Forty-eight (48) Low pressure high efficiency UV lamps (500 Watts each):
        - Using the TrojanUV Solo Lamp™ Technology

- Automatic filter cleaning
- Automatic lamp cleaning
- One (1) UVI sensor
- One (1) Temperature sensor
- One (1) Level sensor
- Two (2) Pressure sensors (inlet & outlet)
- De-Aerators
- Drain assembly

Treatment Unit Cabinets

Power Distribution Cabinet

- Houses the main system power, and breakers.
- Distributes power to all components of the treatment system.

Control Cabinet

- Houses the PLC and other system control function components. The control switches and HMI are mounted on the door of the cabinet.

Lamp Driver Cabinet(s)

- Provides a clean environment for the lamp drivers and connection for all lamp cables.

Pneumatic Cabinet

- Contains all solenoid valves, and pneumatic controls for valves.

Hydraulic Cabinet

- Provides all required hydraulic components for the lamp cleaning system.

*Note: All cabinets are wall mounted*

## Detailed Process Description

### Filling

Depending on the mode of operation (ballast or deballast) the inlet or de-ballast inlet are opened to allow water to be moved into the treatment unit. Water can enter the system by gravity, with the ballast pump, and or an alternative filling pump. All other valves remain closed until the treatment unit is full, triggered by the level switch. While the treatment unit is full the lamp cleaning sequence is initiated. The duration of the filling sequence varies for each installation type and associated piping. When the system is full the outlet valve is opened and ballast water can begin to flow.

### Automatic Lamp Cleaning System

Lamp cleaning initiates automatically. Typically cleaning sequence is initiated at the start of a filling sequence and at the end of a cycle. Ultraviolet lamps incorporated in all ballast water treatment systems are housed in quartz sleeves. These quartz sleeves can become fouled with debris on the sleeve surface reducing the amount of ultraviolet light available for treatment. The lamp cleaning system removes any fouling that could build up on the lamp sleeves. The lamp cleaning sequence is initiated automatically at the start and end of ballast or a de-ballast cycle and based on the time of operation. The system does not need to be stopped during a cleaning cycle.

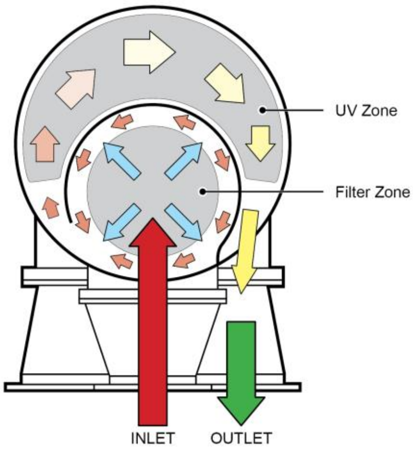
The automatic lamp cleaning system is sequentially driven. Each lamp wiping mechanism consists of a wiper plate, wiping seals and a drive cylinder. The drive cylinder moves the wiper plate with wiping seals from one end of the lamp sleeve to the other. A cleaning sequence consists of actuating the lamp cleaning system from its home position to the end of the lamp sleeves and back to the home position. The cleaning cycle is finished when the last lamp wiping mechanism reaches its home position. The benefit of having the cleaning process sequentially driven reduces disruption to flow and allows the ballasting or deballasting process to continue.

Each drive mechanism is magnetically coupled to a hydraulic drive cylinder. The drive cylinder is hermetically sealed to prevent the possibility of fluid loss. The carriage of the drive cylinder is home to the wiper plate and is magnetically coupled to the cylinder. All hydraulic connections are located on the outside of the treatment unit (non wetted area). Hydraulic fluid used to drive the cylinder ensures a smooth cleaning cycle.

Extensive development has gone into the design of the sleeve to support the lamp technology. Quartz is used as the sleeve material. Quartz is used in this application because it has a low thermal expansion, high thermal shock resistance, good dielectric properties, chemical inertness and good high temperature properties. Most importantly, it has a very high transmission of UV light.

**Ballasting**

The ballast sequence of treatment process occurs when the inlet valve is opened, allowing ballast water to enter the treatment unit. Filtration is the first stage in the treatment process. Filtration removes particles and targets larger organisms, while providing an evenly distributed flow of the ballast water into the UV section of the treatment unit. Filtered water flows through the UV section of the treatment unit targeting all organisms not removed in the filtration process. The treated water is directed to the ballast water tank through the ballast water outlet.




BALLASTING

**Automatic Filter Cleaning System**

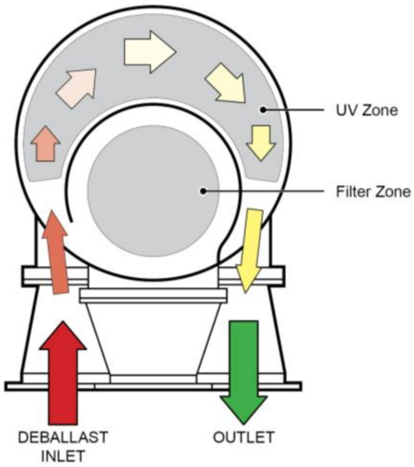
Each treatment unit is equipped with an automatic filter cleaning system. The cleaning system initiates when differential pressure is measured across the inlet and outlet of the ballast water treatment system. Each treatment unit has two pressure sensors, one located on the ballast water inlet and the other on the ballast water outlet. These pressure sensors provide a signal to the control panel to initiate a cleaning sequence. The cleaning sequence consists of opening an actuated backwash valve and signaling the filter drive motor to make one revolution. Each revolution of the drive motor allows each filter element to reverse its flow allowing accumulated debris trapped by the filter to be carried out to drain.

During the cleaning cycle, a flow meter is used in conjunction with a regulating valve to maintain consistent flow rate through the treatment unit. The treated rated capacity can be maintained while the system is in a filter cleaning cycle.

The cleaning system removes a filter from the process and allows filtered water to be diverted back across the filter removing trapped debris. The debris that is dislodged is then diverted back to its original source water. As each individual filter element is cleaned, the remaining filter elements continue to process water. Once the filter drive motor has completed its cycle, the backwash valve closes completing the cleaning sequence.

## De-ballasting

The final stage of the treatment process occurs during de-ballast. Previously treated water (filtered + UV) is moved from the ballast tank to the de-ballast inlet of the treatment unit. During this final stage the water only moves through the UV portion of the treatment unit and then discharged to sea.



DEBALLASTING

## Emptying

When ballast or de-ballasting events are completed, all valves to the treatment unit are closed. The drain assembly will open. All water in the treatment unit is removed to improve the environment for corrosion protection.

## Treatment Unit Design

Trojan Marinex has developed a comprehensive product suite based on the integrated design and offers a full range of discrete flow models to minimize capital and installation costs. This eliminates the need to put many small systems together for large installed applications. The design of each discrete flow model has been optimized for the maximum flow and very challenging water quality conditions. Advanced tools such as Computational Fluid Dynamics and Intensity Models are utilized to optimize the design. These tools increase the efficiency of the overall system resulting in a reduction in environmental footprint. For example, the placement of the filter elements within the unit ensures laminar flow into the UV section of the treatment unit, which ensures proper exposure to the UV lamps for the most efficient disinfection treatment.

The treatment unit is designed to work with ballast pumps at a maximum working pressure of 6 bar. Working pressure of 6 bar typically exceeds the pressure rating of most vessel ballast water management systems.

The treatment unit including the mounting legs has been engineered and reviewed by third party finite element analysis (FEA) for pressure operation, structural analysis of the legs considering pitch, roll and heave. The treatment unit follows documented weld practices for to allow for repeatable weld quality.

## Ultraviolet Intensity (UVI) Sensor

Every flow model is equipped with a UVI sensor to monitor the UV output of the lamps. In the event of low UV output, the system immediately triggers a cleaning cycle. If the condition is not resolved after a cleaning cycle an alarm condition is initiated to warn of the potential for insufficient treatment. The sensor that has been chosen follows a European standard for monitoring the intensity of the UV output.

### Level Sensor

Every flow model is equipped with a level sensor. The level sensor is used to indicate water level conditions in the treatment unit. The level sensor acts as the primary safety indicator to prevent unwanted conditions in the treatment unit such as trapped air that can cause unwanted temperature conditions.

### Pressure Sensor

Every flow model is equipped with two pressure sensors. One sensor is located on the inlet and the other sensor is located on the outlet of the treatment unit. These sensors work in conjunction to sense the differential pressure across the filtration system and act as a detection method for over pressurization. When the differential limit condition is met this triggers a filter cleaning sequence.

### Temperature Sensor

Every flow model is equipped with a temperature sensor to monitor high temperature conditions. The temperature sensor provides a secondary means of safety (level sensor is primary) to prevent unwanted high temperature conditions.

### Control cabinet

The control cabinet is home to electronic components that control the Ballast Water Treatment system. Some of the major components in this cabinet include; the programmable logic controller (PLC) and the human machine interface (HMI). The PLC is programmed with specific code to carry out the automated processes and monitoring functions. The HMI commonly referred to as a touch screen, allows access to various functions and settings, including automatic and manual controls. The touch screen serves as the systems monitoring window. An operator can view all aspects of operation and status at a glance. Additionally, the control cabinet can be interfaced with the ships SCADA system.

### Power distribution cabinet

The power distribution cabinet houses main system power and breakers for distribution and protection of all system cabinets.

### Lamp driver cabinet

The lamp driver cabinet is home to the lamp drivers that provide power to the lamp. The lamp driver footprint simplifies design and installation. The compact driver cabinets allow increased layout flexibility for installation in any location on board a vessel.

Each lamp driver contains advanced controls to maximize the lamp life. The lamp driver has high electrical efficiency (>95%) and reduces wasted energy and necessary cooling requirements. Each lamp driver has on-board digital signal processor to simplify diagnostics, improve reliability and improve the lamp life and UV output. Each driver comes equipped in a rack-mount design simplifying maintenance. Power and communication signals connect automatically when lamp driver is inserted – no manual wiring is required.

### Pneumatic cabinet

The pneumatic cabinet provides distribution to all the valves.

### Hydraulic cabinet

The hydraulic cabinet is home to the electric motor, pump, and hydraulic solenoid valves. The hydraulic connection points at the treatment unit are quick disconnection type.

**Monitoring**

The system automatically monitors and logs key components of the treatment process. This data must be stored for a 2 year period. The data logging will occur when the ballast water treatment system is operational or by-passed. Data is easily retrievable electronically via a CSV file.

**Alarm Conditions**

Equipment alarms have been broken into three categories. These alarms have been broken down into three categories.

Critical Alarms ~ Impact safety and operation of the vessel
Major Alarms ~ Impacts the operation of the ballast water treatment equipment.
Minor Alarm ~ Potential impact to the operation of the ballast water treatment system.

**Safety Features**

The UV portion of the treatment unit has safety features that have been developed to prevent personal injury:

- Lamp plug interlock - The design of the lamp sleeve assembly and lamp plug prevents a user from removing a UV lamp or a lamp sleeve assembly from the treatment unit while the lamp plug is connected to the UV lamp.
- Lamp plug disconnect - The electrical power supplied to a lamp plug is disconnected when the lamp plug is removed.
- Door limit switch - A limit switch removes power to the lamp drivers when the lamp driver cabinet door is opened.

## Assembly & Manufacturing

Each treatment unit is pressure tested beyond its working pressure to ensure confidence in the designed working pressure in order to meet the assembly craftsmanship.

Each wiper drive cylinder is factory tested to ensure good working order.

## 2. System Information

| | | |
|---|---|---|
| **General** | | |
| Treated Rated Capacity | 500 $m^3$/h per unit | |
| Number of lamps | (48) Forty-eight | |
| Lamp Type | TrojanUV Solo Lamp™ | |
| Sleeve cleaning | Automatic sleeve cleaning | |
| Lamp Power each (watt) | 500 | |
| Typical Electrical requirements | 26.1 kVA | |
| Number of filters | (24) Twenty-four | |
| Minimum Flow Rate | 50$m^3$/h | |
| Maximum Operating Pressure | 6 bar | |
| Water temperature range | 2°C to 40°C continuous (sea water)<br>• No slush or ice | |
| **Treatment Unit** | | |
| Material | 316L stainless steel construction | |
| Filter information | 1.5 bar minimum inlet pressure<br>0.05 bar pressure differential clean filter elements<br>0.25 bar pressure differential to start cleaning cycle | |
| Filter cleaning duration | Approximately 25 seconds per cleaning cycle. | |
| Filter cleaning frequency | Varies depending on the local water quality | |
| Lamp sleeve cleaning | Approximately 1 minute per cleaning cylinder | |
| Lamp cleaning cylinders | Three (3) magnetically coupled hydraulic cylinders | |
| Lamp cleaning frequency | At the start and end of every cycle and based on time | |
| Weight | Approx. 2,100 kg dry<br>Approx. 3,200 kg wet | |
| Hydraulic connections | Ballasting inlet | Flange DN300 PN10 |
| | De-ballasting inlet | Flange DN300 PN10 |
| | Outlet | Flange DN300 PN10 |
| | Backwash | Flange DN150 PN10 |
| | Unit drain | Flange DN50 PN10 |
| | | |
| Installation orientation | Vertical | |
| Serviceability | Vertical ~ from the top | |
| Instrumentation | 1 UVI Sensor, 5m cable length | |
| | 1 Level sensor, 5m cable length | |
| | 1 Temp sensor, 5m cable length | |
| | 2 Pressure sensors (Inlet and outlet) 5m cable length | |
| **UV** | | |
| Lamp type | TrojanUV Solo Lamp™ | |
| Lamp power | 500 watt / lamp | |
| Number of lamps | 48 | |
| Cleaning | Automatic sleeve cleaning is standard | |
| Drive cylinder qty | Three (3) | |
| **Sleeve** | | |
| Sleeve type | Marine tube class | |
| Material | Quartz | |
| Length | 1m | |
| End | Domed | |
| Holder | Flaired | |
| Sleeve wiper | standard | |
| Number of sleeves | Forty-eight (48) | |

| | |
|---|---|
| **Filtration** | |
| Number of filter elements | Twenty-four (24) |
| Filter material type | Super Duplex mesh |
| Sealing surface | EPDM O-ring |
| Tools required | No tools required to remove a filter |
| **Filter Cleaning System** | |
| Design | Upper and lower cleaning arm |
| Material | 316L stainless steel |
| **Control Cabinet** | |
| Quantity | One (1) per treatment Unit |
| Configuration | Stand-alone cabinet |
| Dimensions (W x H x D) | 800 mm x 1000 mm x 300 mm<br>Wall mounted standard |
| Controller type | PLC with touch screen interface |
| Communication protocol | Ethernet/IP standard<br>Modbus RS485 |
| Electrical supply | 240 V single phase, 2 wire (No Neutral) + GND, 50/60 Hz, 2.0 kVA |
| Max distance between control cabinet & lamp driver cabinet | Approx. 100 m standard (running distance) |
| Rating | IP54 standard |
| Materials | Powder coated mild steel standard |
| Weight | Approx. 65 kg |
| Programmable Logic Controller Type | M340 Modicon |
| Human Machine Interface Type | Modicon Magelis |
| **Power distribution cabinet** | |
| Electrical supply | 240V, 3-phase, 3 wire (No Neutral) + GND, 50/60 Hz |
| Quantity | One (1) per system |
| Configuration | Stand-alone cabinet |
| Dimensions (W x H x D) | 800 mm x 1000 mm x 300 mm<br>Wall mounted standard |
| Weight | Approx. 64 kg |
| Rating | IP54 Standard |
| Materials | Powder coated mild steel standard |
| **Lamp driver cabinet** | |
| Common name | Lamp driver cabinet |
| Quantity | Two (2) per treatment unit (air or liquid cooled) |
| Configuration | Stand-alone cabinet |
| Dimensions (W x H x D) | 600 mm x 620 mm x 600 mm (air cooled)<br>Wall-mount standard |
| Cable length (running distance) | 10 m standard |
| Communication Type | Modbus RS485 Communications |
| Driver cabinet weight | Approx. 80 kg (air cooled) |
| Local disconnect | Internal disconnect standard |
| Rating | IP54 standard |
| Number of drivers | Two cabinets with six (6) lamp drivers |
| Materials | Powder coated mild steel standard |
| Cooling | Air or Liquid cooled is available |
| Air Cooling Requirements | Clean, dry compressed air |
| | Approx. 140 CFM at 6 bar |
| **Pneumatic Cabinet** | |
| Quantity | One (1) per treatment unit |
| Configuration | Stand-alone cabinet |

| | |
|---|---|
| Dimension (W x H x D) | 600 mm x 381.5 mm x 210 mm<br>Wall-mount standard |
| Control Cable distance between treatment unit & cabinet (running distance) | 20 m standard |
| Pneumatic hose rating | 0 deg C to +80 deg C |
| Weight | Approx. 33 kg |
| Rating | IP54 standard |
| Materials | Powder coated mild steel standard |
| Air Supply Required | Varies depending on valves used and distance from cabinet. |
| **Hydraulic Cabinet** | |
| Quantity | One (1) per treatment unit |
| Configuration | Stand-alone cabinet |
| Dimension (W x H x D) | 600 mm x 631 mm x 300 mm<br>Wall-mount standard |
| Hydraulic Connection type | Quick disconnect at the treatment unit.<br>Female BSPP at the cabinet |
| Hydraulic Cable length (running distance) | 5 m standard |
| Hydraulic Cable rating | -40C to +100C<br>Max working pressure 4775PSI (33MPa).<br>Approved for hydraulic base fluids and lubricating oils |
| Hydraulic fluid type | TELUS T15 |
| Weight | 40kg |
| Rating | IP 54 |
| Materials | Powder coated mild steel |